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A SIMULATION TO ANALYZE PILOT WORKLOAD IN AN ELECTRO-OPTICAL, NIGHT, LOW-LEVEL ENVIRONMENT

Master's THESIS

Anthony W. Groves, Major, USAF
Richard L. Kaercher, Lt Colonel, USAF

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The model was used to compare pilot workload at 1000, 500, and 250 feet above ground level (AGL) with three levels of electronic countermeasures (ECM) service required at each altitude. The result indicated that workload decreased with altitude in a threat environment due to the reduced number of defensive maneuvers required. ECM task reduction did not have a significant effect on pilot workload.

Expansion of the modeled profile to include the weapon employment phase was recommended. Alteration of the model to incorporate mission success probabilities and aircraft equations of state to determine minimum flight control inputs were also recommended.

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A SIMULATION TO ANALYZE PILOT WORKLOAD IN AN ELECTRO-OPTICAL, NIGHT, LOW-LEVEL ENVIRONMENT

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science

by

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Graduate Strategic and Tactical Sciences

March 1981

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Preface

Pilot workload has been a steadily increasing problem in fighter aircraft as technology has allowed more capable and more complicated systems to be integrated with aircraft. Both of us have seen this problem in the F-4 where over the years systems were added to it which gave it more capability and also increased the workload of the crews. The question of how much workload is too much will eventually have to be answered. This project was selected by us because we felt that with our operational flying experience combined with the analytical and simulation methods plus the techniques which we gained from the Strategic and Tactical Science Course at AFIT we could develop a basic method with which to begin to evaluate pilot workload.

We want to thank the personnel at the Wright Patterson Cockpit Design Facility for allowing us to use the A-10, LANTIRN, Cockpit Design Simulator to gather the data for aircraft control movements without which this project would not have been possible. We also want to thank our advisor, Lieutenant Colonel Tom Clark, who guided us during the course of the project. We express special thanks to our wives and families for their love and patience without which the past eighteen months would have been intolerable.

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Abstract

As new equipment is developed for fighter aircraft, new mission profiles are often developed. One method of evaluating the change in pilot workload associated with this new equipment is the development of a man-machine simulation that will allow workload comparisons. This thesis undertakes the development and application of such a model.

The model developed and used in this study is a time sequenced network of required tasks with priority servicing by a single server. Monte Carlo techniques are used to induce randomness into the profile to represent the variation between individual missions and pilot techniques. The major parameters in the model are the flight control service times, frequency of flight control task initiation, and the frequency of defensive reaction task initiations. The model incorporates twenty different tasks in a mission profile simulating thirty minutes of night tactical low-level navigation using an electro-optical device for visual navigation and terrain following.

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Expansion of the modeled profile to include the weapon employment phase was recommended. Alteration of the model to incorporate mission success probabilities and aircraft equations of state to determine minimum flight control inputs were also recommended.

A SIMULATION TO ANALYZE PILOT WORKLOAD IN AN ELECTRO-OPTICAL, NIGHT, LOW-LEVEL ENVIRONMENT

I. Introduction

Background

The united States Air Force, until now, has had no low-level night attack capability with its primary attack aircraft. The night capability has been limited to radar navigation or dead reckoning to a target area at an altitude above all terrain along the route. Employment of weapons has also been seriously degraded at night because of visual restrictions. Equipment is presently being developed that will enable a single crew member aircraft such as the A-10 or F-16 to operate in the night low-level arena. The equipment will provide a video presentation on a Heads-Up-Display (HUD) of a sector of view in front of the aircraft. The presentation is proposed to appear three-dimensional and of high enough resolution to allow very low altitude (250 feet) navigation and terrain avoidance at night in clear weather or below clouds. The HUD will present a sector scene with terrain features depicted in the same location and of the same size as they would appear if seen in the day through the windscreen. The equipment has the potential of increasing the night operational capability of single seat tactical aircraft. In conjunction with increasing the night capability of aircraft, technology has allowed electrical subsystems to be reduced in size; this in turn has provided more room for equipment in the aircraft which potentially increases pilot workload.

Pilot workload is becoming a concern to many agencies (Ref 13) such as Air Force Studies and Analysis and Aeronautical Systems Division/Equipment Engineering. The need to evaluate a system's potential effect on workload prior to the purchase of the system has become very important, particularly in an age of high cost systems and emphasis on reduced budgets.

Currently there are three main methods of evaluating pilot workload for new systems and mission profiles: (1) subjective opinion by experienced pilots concerning the workload, (2) use of weapon system simulators for workload measurement, and (3) modification of existing weapon systems to perform as the proposed systems for testing by pilots who are experts in ergonomics and cockpit design. The first method is very subjective and tends to restrict innovative ideas. The second method is expensive because it requires sophisticated simulators which are expensive to construct and modify. A point that is often overlooked is that simulators lack the element of danger associated with actual flight. The simulated environment and lack of danger could lead to testing ideas that would not have been considered in actual flight tests. However, one negative result of buying a system which had only been tested in the simulated environment would be to find that the system was too dangerous for a pilot to operate in actual flight. The third method, modifying existing systems, is the most effective but also the most hazardous, expensive, and time-consuming.

Man-machine simulation is a possible alternative method of evaluation of pilot workload. Although it would not be wise to purchase a system based solely on the results of a workload simulation, the simulation model could be very useful in identifying blind alleys, bottlenecks, and theoretically potential areas or ideas. Many types of human activities have been modeled in the past but were not successful because too many factors and variables had to be considered. Today, with better computers and progressively more sophisticated simulation languages such as SAINT (Ref 9) and SLAM (Ref 8), man-machine simulations are becoming more feasible. A simulation of a single pilot flying a tactical low-level navigation mission at night could be very beneficial in evaluating proposed night attract systems.

Problem Statement

In the Night All Weather A-10 Flight Test Pilot Report, two test pilots expressed their opinion of the pilot workload in the night low-level environment (Ref 1). As experts in flight test of new systems, they stated that workload at 1000 feet AGL (the altitude flown in the test) was very high. They also stated that they felt workload at lower altitudes would be beyond pilot capabilities. In another portion of the report they expressed a need for a threat management system for tactical missions to relieve the pilot of the task of electronic countermeasures (ECM) activities. A simulation of this mission at altitudes of 1000, 500 and 250 feet with varying ECM task levels could be used to extend the analysis of pilot workload in this potential flight regime. Although this thesis addresses the specific problem mentioned above, the underlying purpose of the research study is to demonstrate a methodology for man-machine simulation in the workload analysis field.

Scope

This thesis deals with modeling the physical activities required of a pilot on a tactical low-level navigation mission using a limited field of view video Heads-Up Display (HUD). The modeled profile does not include weapon employment or target acquisition. Although it addresses the impact of stress due to enemy threat systems and altitude flown above ground level, the model does not address the impact of the pilot's mistrust of the system, the anticipated vertigo-inducing effects of the HUD or external visual distractions, the discomfort/anxiety associated with manual terrain following and maneuvering using a reduced visual field or any equipment malfunctions.

Objectives and Research Design

The objective of this study was to provide an example of the utility of a pilot-aircraft simulation model to examine pilot workload. The specific objectives were to develop a model that demonstrated feasible methodology for collecting interval data on a pilot-aircraft system and to demonstrate the use of that data in making workload comparisons.

The research design used in this study is shown in Figure 1. The first three steps included defining the problem and mapping this research design, defining the low-level mission characteristics and the specific mission profile, and forming the overall model concept and structure. The model parameter determination and model computerization was an iterative process as shown in Figure 1. Estimated parameters were refined after being used in the model if their contribution was significant in the overall results. The seventh step involved exercising the model in accordance with the experimental design so data analysis could be accomplished in the next step. After data were analyzed and discussed, the research design terminated with the presentation of conclusions and recommendations.

Assumptions

The following assumptions were made for the purpose of bounding this thesis to a manageable study.

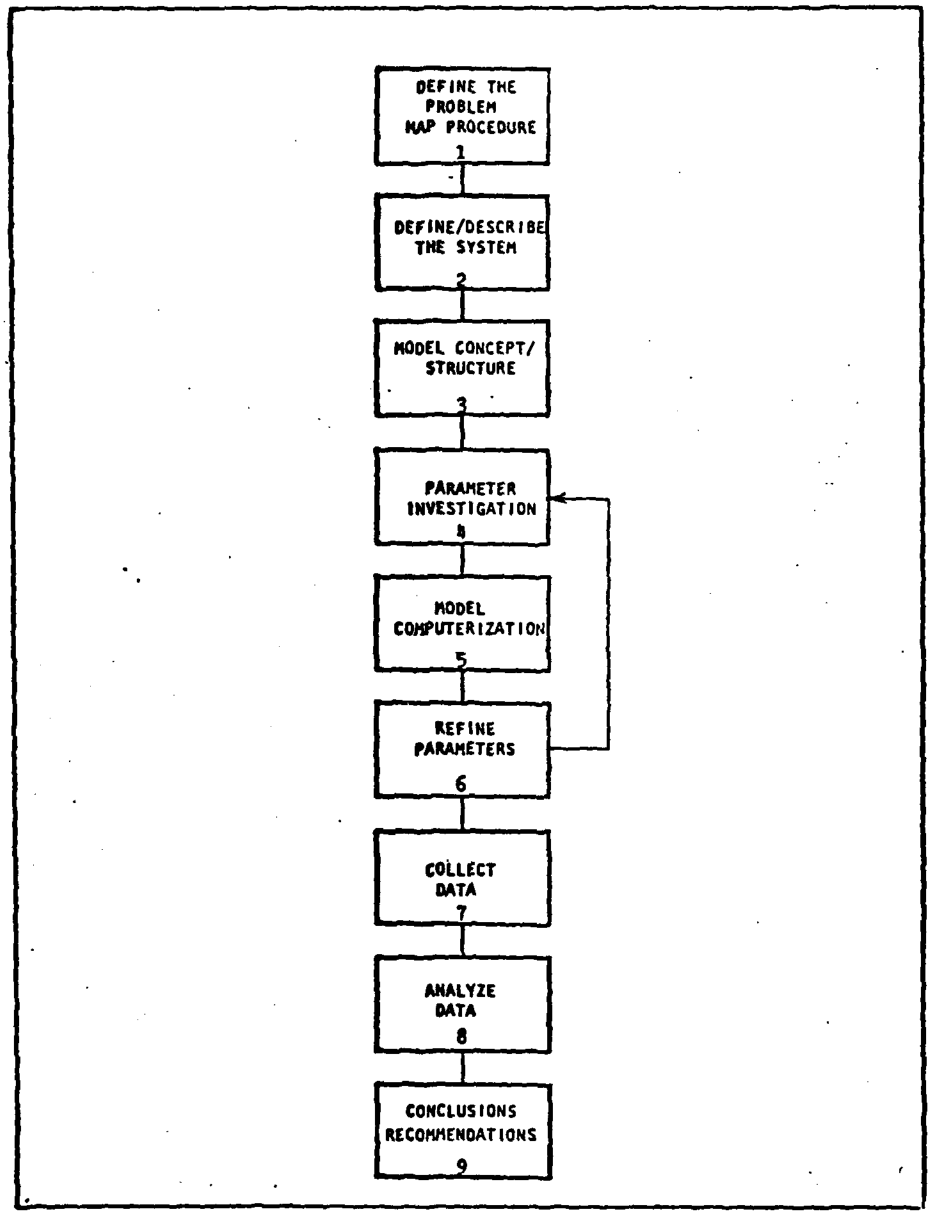

Fig. 1. Research Design

1. A pilot is a serial processor of assigned tasks. These tasks may be interrupted and restarted many times but parallel task processing is not possible.

2. Tasks are serviced or preempted on a priority basis and the priority is always obeyed.

3. Some tasks must be performed prior to an event taking place in the profile while other tasks may await service for extended periods of time. Not all tasks are critical to survival or accomplishment of the mission.

4. The mission begins at a known, desired point and the pilot and aircraft survive the threat posed by enemy defensive systems through profile termination.

Overview

The remainder of this thesis is devoted to the accomplishment of the objectives specified earlier. Chapter II contains an explanation of the mission concept and develops the model profile. The model and the model parameters are described in Chapter III while Chapter IV contains the development and collection of data used in determining the flight control task parameters. Data collection is covered in Chapter V. Data analysis and results are contained in Chapter VI. The final chapter presents conclusions, recommendations and suggestions for expanding the scope of pilot modeling.

II. Mission Concept

A night, low-level navigation mission in a combat environment is modeled in this thesis. The model specifically addresses the navigation portion of a combat profile with no reference to takeoff, target acquisition, weapons employment, or recovery. The mission begins at a start point and proceeds for thirty minutes. Threat reactions are treated; however, aircraft malfunction, mission abort, or aircraft destruction are not allowed. On actual flights, many different pilot techniques are used to accomplish tasks which are necessary to obtain the highest probability of survival and mission success in night low altitude navigation. The tasks can be grouped into families based on the task purpose, each family having a different level of importance. This chapter is devoted to a general discussion of the tactical low-level navigation mission and a description of the specific mission modeled. A mission description is necessary to show how the similation was built around the modeler's mission concept.

Tactical low-level navigation is accomplished by a pilot in a single cockpit aircraft performing a sequential set of activities or tasks. The procedural nature of the mission lends itself to the design of cycles of time to accomplish sequences of tasks which will most efficiently use the pilot's limited time and provide cues for the pilot to accomplish tasks that might be forgotten. The tasks can be grouped into four main areas which are based on the objectives of the tasks (see Figure 2). The tasks are grouped by their relation to: (1) aircraft control, (2) navigation, (3) monitoring and operation of aircraft systems, and (4) tasks associated with recognizing and countering enemy threat systems. Aircraft control tasks are movements of the flight controls, stick, throttle(s), and rudder, which cause the aircraft to perform as desired by the pilot. They are important and must be accomplished frequently in the low altitude environment to avoid hitting the ground. A repeated failure to accomplish these tasks over just a short period of time would result in the destruction of the aircraft and loss of the pilot.

The second group of tasks have to be performed if the pilot wants to know where he is, where he is going, or how to get to a desired location. Airspeed, heading, time, present location, predicted location, and distance to the predicted location, all relate to information that must be known by the pilot for him to successfully navigate the aircraft. The tasks in this group are, in some cases, as simple as looking at a clock or instrument and interpreting the information provided by the instrument. Other tasks are more complicated and time-consuming. Some examples are updating the inertial navigation system (INS), selecting the desired coordinates on the INS of the point to which

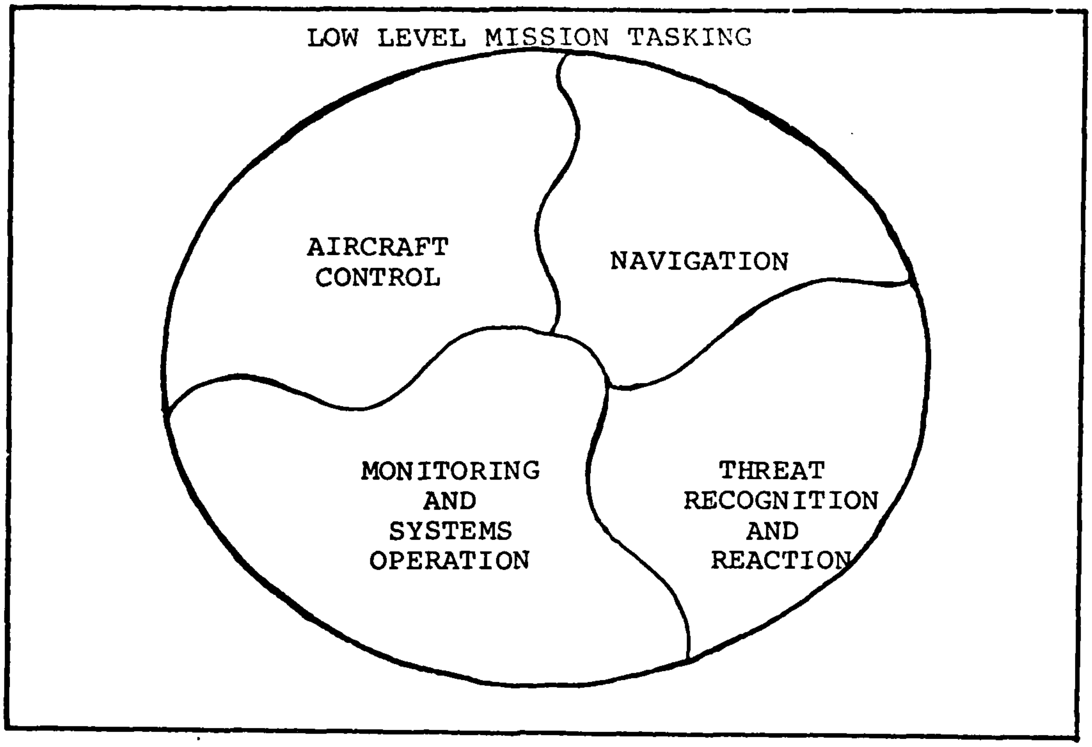

Fig. 2. Task Grouping

the pilot wants to fly, and map reading. All these tasks relate to aids to navigation. Classical navigation, dead reckoning (DR), will not be used as the primary means of navigation in the tactical night low altitude environment. DR requires that the pilot start at a known location and fly a constant heading for a planned period of time to arrive at a predicted location. The classical technique of DR is not feasible for a night low-level mission in a hostile environment. Optimum use of terrain features and reactions to enemy threat systems will not allow a pilot to maintain the constant heading or speed required for DR navigation. Electronic aids to navigation must therefore be used to allow aircraft maneuvering and rerouting of the mission in the night low altitude environment. The time required for a pilot to operate the electronic navigation aids requires less effort for the increased capabilities than classic DR navigation.

The third group of tasks is the systems operation group. It is broad and in some cases the tasks might seem to overlap the other groups, particularly navigational tasks. Typical tasks in this group include switch changes for fuel transfer and INS update. INS update overlaps the navigation task group, but in this case it is treated as a task required to insure that the INS system is operating properly. An "OPS Check," which is a collection of tasks performed to insure that an aircraft and its important systems are operating properly, is also in this group. Examples of items in an "OPS Check" are checks of the engine instruments, fuel state, malfunction telelite panel, and the pilot life support systems. The tasks in group three can be neglected for varying periods of time. However, the longer the period between checks the greater the possibility of serious problems going undetected. These problems could induce errors in navigation, allow fuel starvation, or affect aircraft flight control systems. The failure of a pilot to be aware of any potential problem could lead to more serious problems which could eventually cause the destruction of the aircraft and the death of the pilot.

The fourth group deals with threat tasks. The first three groups pertained to all low level navigation missions, the fourth relates to only tactical missions in a hostile environment. The tasks associated with this group involve recognizing visual or electronic indications of enemy threat systems and initiating defensive maneuvers or selecting electronic or decoying methods to counter the threat. The critical nature of each of these tasks varies depending on the seriousness of the threat. Failing to notice a need or failing to adequately accomplish a task relating to a threat may have no impact, but would likely result in the imminent loss of the aircraft and the pilot.

The above information is used as a base for the concept of the modeled mission. The remainder of this chapter deals with the specific profile modeled and the rationale for including each task in the model.

The navigation mission modeled begins on the friendly side of the Forward Edge of the Battle Area (FEBA) and proceeds across and beyond the FEBA. The average mission has four turn points and five legs (path flown between turn points), each leg being approximately seven minutes long. During the mission the pilot processes tasks from each of the four previously-mentioned groups. Tasks from the aircraft control group are those that the pilot uses to maintain aircraft control. These are the most important tasks in that they must be performed very frequently or the aircraft will deviate too far from the intended flight path which would result in the aircraft striking the ground. The movements of the flight controls by an experienced pilot are the direct result of the pilot's perception of the cues on the HUD. The cues are in two forms, the visual presentation of the terrain in front of the aircraft and indicators which show the pilot and aircraft's airspeed, attitude, altitude AGL, and navigation information. The visual presentation shows a view of the terrain in front of the aircraft in a section thirty degrees wide and twenty degrees high. The depth of view displays objectives between 3000 and 30,000 feet ahead of the aircraft under ideal atmospheric conditions. In the course of a mission the pilot must almost continuously move the flight controls to guide the aircraft along the intended three-dimensional path he wants it to follow. Specific tasks contained in the mission concept of flight control task group besides flight control movements are turns required at the navigation points and defensive maneuvers which are necessary at random points in the mission to counter enemy threats. At all turn points, flight control movements are part of the tasks required to turn the aircraft; however, they are not the same movements used by the pilot in straight-line navigation between turn points.

The same is true of defensive maneuvers. The pilot uses flight control inputs to control the aircraft but again the inputs are not the same type used to control the aircraft in straight-line navigation.

Navigation tasks relate to flight control tasks in that without a knowledge of an intended course from the present location the pilot would not know how to move the flight controls to navigate the aircraft. Navigation tasks are those tasks that must be accomplished by a pilot to maintain, check, and update navigational aids such as the INS, clock, airspeed indicator, and heading indicator. Mission success and survival depends on precise navigation to place the desired turnpoint or target within the limited view of the video sensor. Should a target or turnpoint not be within the field of view of the video system, the probability of mission success would be reduced, if not totally negated. DR, the classical form of navigation, is not included in the mission concept for the reasons previously mentioned. Failure of the navigational aids is not addressed in the mission concept because it would not contribute to the study of pilot workload on the mission. This is based on the belief that a mission abort would result from such equipment failures.

The aircraft systems monitoring and operating tasks are accomplished on an as-time-permits basis. These tasks are accomplished by a pilot to insure the proper operation of the aircraft and its subsystems. They are monitoring tasks more than manipulating tasks. Monitoring fuel remaining, observation electronic countermeasure (ECM) systems, and INS indications are examples of specific tasks in this group. Crosschecks of the displayed HUD information with cockpit instruments to confirm correct airspeed, aircraft attitude, altitude AGL, heading, and navigation information to the next turn point are key tasks which a pilot uses to confirm the accuracy of and maintenance of his confidence in the video and HUD system. OPS checks are also required tasks in this group. Most pilots have a sequence they use to accomplish all these tasks in an on-going cyclic manner. They are usually initiated at points in the mission where control of the aircraft is less critical and the attention of the pilot can be safely diverted for very short periods, sufficient for the pilot to analyze what an instrument is indicating.

In the course of a combat mission, threats will be present. The final group of tasks are those where the pilot is involved in detecting, monitoring and reacting to threat indications from the Radar Warning Receiver (RWR) and visual threat sightings. They also include actions taken to decoy the threat systems with chaff or flares from countermeasures pods.

The tasks mentioned in this discussion are the only type tasks to be modeled. Other tasks could easily be included to adapt to profile changes or equipment modifications. These tasks, however, were considered to be an accurate representation of tasks required on a low level mission in a hostile environment. This judgement was based on a combined experience of the modelers with over 5000 flying hours in the tactical operation of F-4 and F-5 aircraft in three major tactical commands and 900 flying hours of combat experience. The specific task service times and frequency of task requirements are discussed in Chapter III.

III. The Model

Introduction

The thesis model is described in this chapter by presenting the basic model concept, the mechanics of the four segments of the model structure, the specific model parameters and the validation and verification process used to establish confidence in the model. Model flow charts, network diagrams and a documented computer code listing are contained in Appendices A and B. A new simulation model was developed for this study because no existing models addressed pilot workload in the low altitude environment.

The model is a time sequenced network simulation employing SLAM (Simulation Language for Alternative Modeling) to model a single pilot flying a thirty-minute night low-level mission in a tactical threat environment. The model utilizes normal, exponential and discrete empirical distributions to initiate the repetitive mission requirements for twenty different tasks and to determine the required task service times. Task servicing is modeled by utilizing queueing and priority servicing of the tasks to determine required and completed service times in order to measure pilot workload. Use of the model allows the comparison of pilot workload based on service time for differing profiles and task servicing requirements of differing equipment configurations.

Model Structure Segments

The network model structure can be divided into four segments. These segments are task input, queueing, service and data output. Each task enters the network via an input distribution based on the task requirement frequency in the actual system. The task proceeds to a queue where it awaits service based on its assigned priority and is serviced by a single server. The task is then routed through an output routine to collect service time information. This basic structure is followed by all modeled tasks but the details of each segment of the model are much more sophisticated than this simple trace implies. Each of the four segments is discussed in detail below.

Task Inputs. Task initiation is based on replicating the actual task sequencing on a representative mission. This sequencing follows four types of initiation loops (Figure 3). The sequencing loops are based on time intervals, location, server availability and pilot perception.

The first input loop represents tasks that must be accomplished on a time interval basis. For example, a navigation point search routine is required periodically to confirm aircraft location. The model uses a normal distribution with a user-defined mean and standard

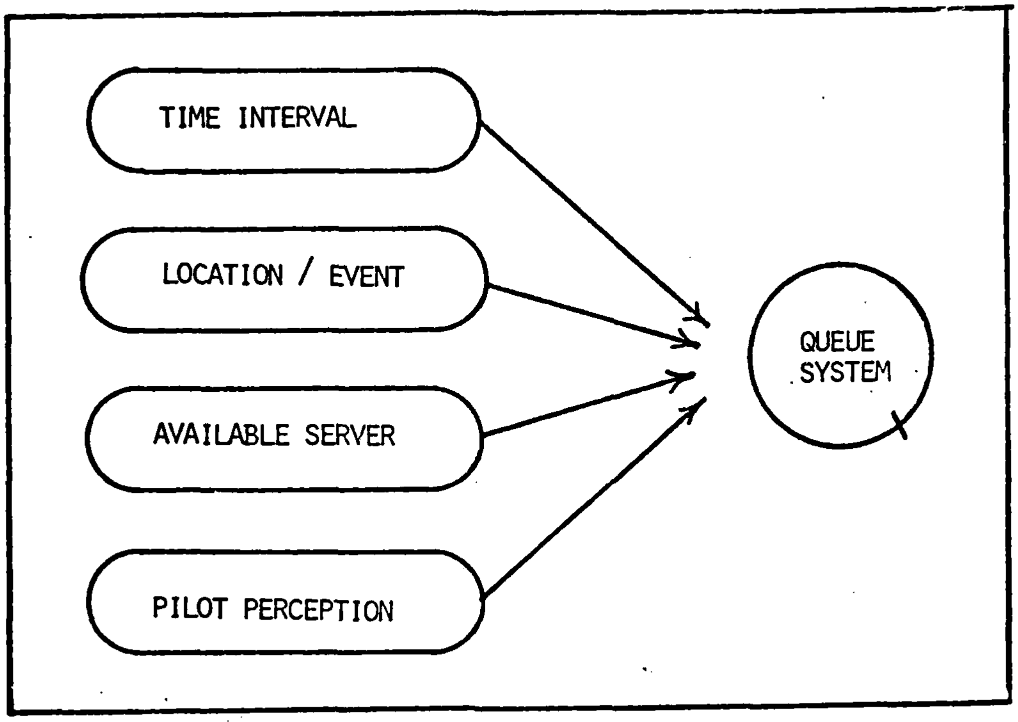

Fig. 3. Types of Task Initiation Loops

deviation to initiate tasks into the system so they may arrive in the queue at an interval with some variability.

The second type of initiation loop is one based on aircraft location. As was mentioned in Chapter II, low-level procedures are often based on inherent cues in the profile to "jog the memory" of the pilot. The tendency, therefore, is to require a series of tasks to be initiated when approaching or departing a planned turn point. A typical example is checking the fuel status at each turn point. Since navigation leg lengths are based on a desired leg time, turn point initiated tasks are based on both aircraft location and time intervals. Some tasks such as defensive reactions are based solely on aircraft location. Location based inputs are initiated in the model by allowing the release of one task to initiate another group of tasks.

The third type task initiation loop is based on tasks that require service during some time period but the specific time of completion is unimportant. For example, crosschecks of information between the HUD and cockpit instruments can be accomplished at any time but they should be accomplished at least once per navigation leg. This is modeled by initiating the task requirement at the beginning of each navigation leg and allowing service anytime along that leg which equates to an available time sequencing. The task is performed when the server is not servicing higher priority tasks. If the task is not accomplished by the next turn point the new task is initiated but is sent to a data collection routine rather than the service queue. The collection routine provides an indication that the task was not performed due to higher priority task servicing.

The last task input sequencing routine is based on the pilot's perceived need for the task. In the case of aircraft control tasks this is modeled by using one discrete empirical distribution for the frequency of task inputs and another for the length of service time. These distributions are interrupted at each turn point by the initiation of a task to turn the aircraft to a new navigation heading. Interruptions are also caused by defensive maneuvers initiated in the defensive reaction routine. The model does not actually halt the flight control distributions but instead removes the aircraft control tasks that entered the service queue while the turn or defensive maneuver was being serviced. The removed tasks are discarded because they are assumed to have been accomplished as part of the flight control manipulations of the other tasks.

All system inputs are based on distribution parameters that are discussed later. The assigning of a task identification number, service time requirement, service priority and a service time segmenting code is accomplished in each input routine.

Task Queueing. The queueing system for this model is required in order to simplify input routines and to allow tasks to await service on a priority basis. The complete queueing system encompasses three queues, each with a differing purpose (Figure 4). The first receives all non-flight control tasks (regular tasks) and continuously reranks them to maintain the highest priority in the first position in the queue. This queue has an infinite capacity and handles each task only one time and releases the task into the service scheme. The second queue is an integral part of the service scheme for regular tasks. This queue has a capacity of one and may handle each specific task many times. The third queue was used for tasks involving flight control movements (critical tasks). This queue has

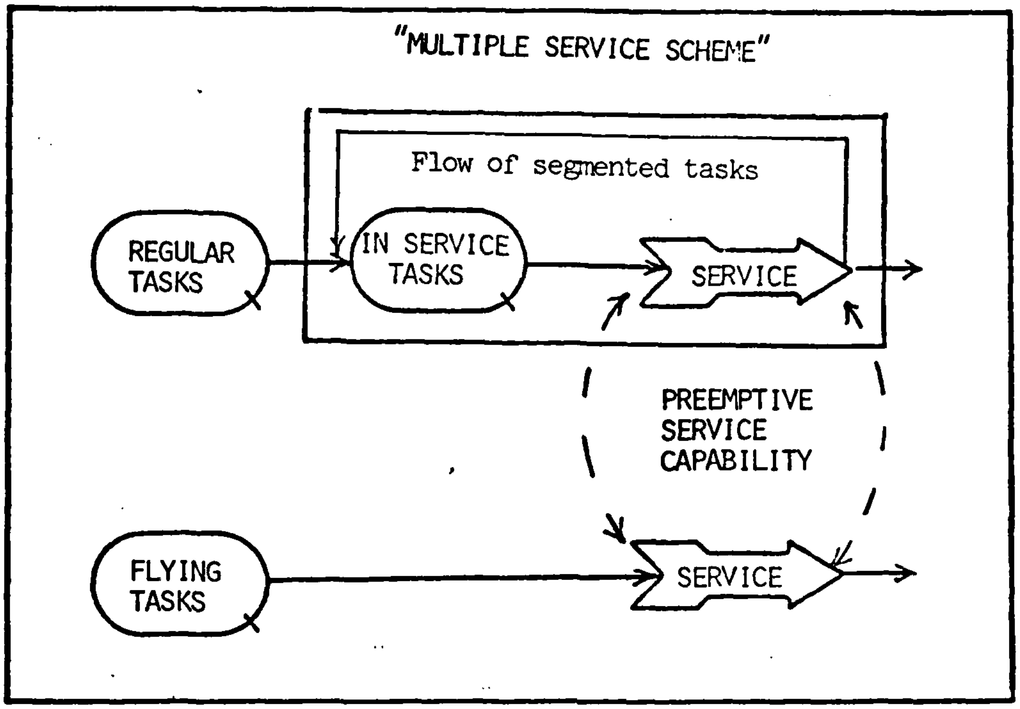

Fig. 4. Queue and Service Diagram

an infinite capacity and a priority ranking system too, but it also allows the tasks entering the system and passing through it a service preemption capability. The preemptive capability was necessary to model the entry into service of critical tasks that require immediate service. The service ramifications of the two different type queues is discussed next.

Task Service. Task servicing involved a scheme of using a single server to perform tasks as they were released from the queues. The sequence of service for a regular task began with its release from the first queue (regular task queue). It then entered the service queue and awaited completion of the previous task. When that task was completed the new task was serviced and released to the output routine. This is an example of the least complex sequence possible in the model service scheme. More sophisticated sequence encompasses the multiple task servicing and task preemption.

As was mentioned earlier, each task was assigned a service time and a service segmentation code when it entered the system. The segmentation code allowed tasks to be marked for more than one service cycle by dividing the required service time into equal user-specified segments. For example, a service time could be divided into three parts. The task would then enter service, complete one third of the required service time and return to the service queue (Figure 4). When the other task in this cycle completed its segment of service time the original task would reenter service for the second third of its total service time and then return to the service queue. This would continue until every segment of the task service was completed and the task would then proceed to the output routine. This "multiple servicing" scheme models the act of beginning one task and momentarily switching between that task and another to accomplish both tasks apparently simultaneously. The total service time for servicing both tasks would still be the sum of the individual task service times but the variance of task servicing delays would be reduced. This scheme is a good simulation of performing tasks that require an activity to initiate service and then a waiting period prior to service completion.

The next level of complication in the service scheme is the initiation of a critical task while a lower priority task is in service. In this case the lower priority task in service is returned to the queue from which it entered service and reranked in that queue with the remaining service time noted for future service. When the preempting task completes service the other tasks begin service again. All preemptive tasks have a segmentation code of one so they receive only one service period prior to the data collection routine.

The final portion of the service scheme is the modeling of the impact of stress on the server. This is accomplished by using the Monte Carlo technique to determine if the task was correctly serviced. A random number is compared to a stress factor parameter and if the random number is greater than the stress factor the task is sent to the appropriate queue to be reaccomplished (Figure 5). Since the incorrect accomplishment of a flight control task creates an additional error in the aircraft position, these tasks were reinitiated twice to model correcting the error and then accomplishing the original task. The stress factor parameter is a variable that decreases as the stress of the mission increases. The amount of decrease is based on the number of ECM tasks required in the last two minutes, the service of a defensive maneuver in the

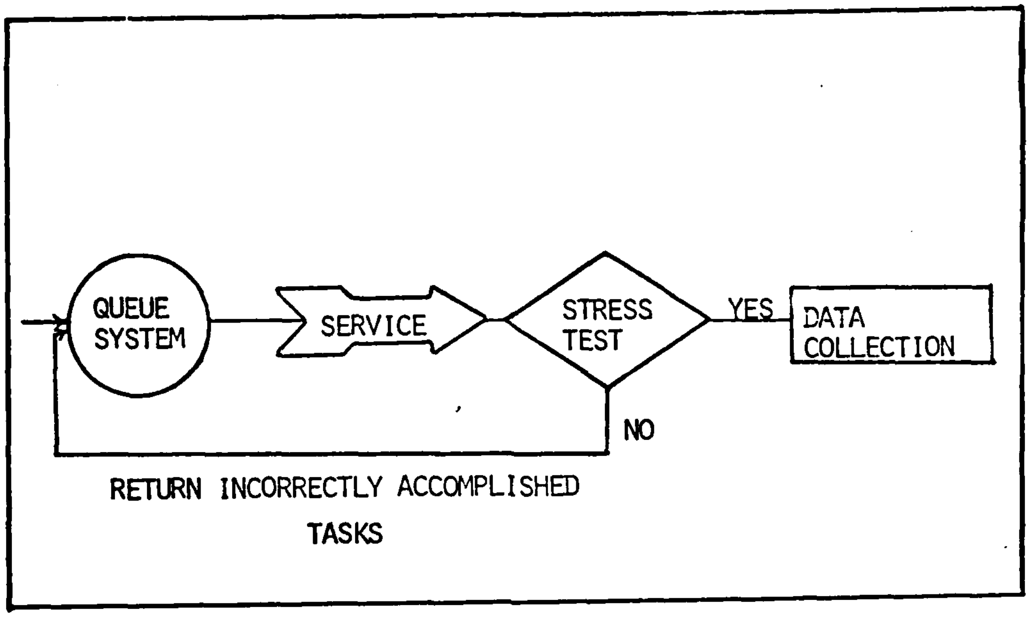

Fig. 5. Stress Factor Scheme Diagram

last ten minutes and the success or failure of the last navigation search routine (this success or failure is also based on a Monte Carlo routine). The no-stress situation value for the stress parameters is .97 (Ref 11:15). The amount of parameter decrease for each factor is shown in Table I. The table values are based on the expert opinion of the modelers.

Model Data Collection and Output. The collection of data pertinent to this study was accomplished in conjunction with the queueing system and the service scheme. As a task entered the queueing system its required service time was collected. This service time was then added to the sum of the previous times for that task and to the sum of the total tasking time. When a task completed service

TABLE I

STRESS PARAMETER DECREASE BY FACTOR

Factor	Amount of Decrease	Comment
Defensive Maneuver	.03	Doubles No Stress Error Rate
Unsuccessful Navigation Point Search	.03	Doubles No Stress Error Rate
ECM Tasking	.0001X (ECM Time)*	

*ECM time = total of ECM task service time over the last 120 seconds.

(each segment of service for segmented tasks), the completed service time was added to the total time of completed tasks of that time and to the total serviced tank time. At the end of each simulation run this data was recorded to allow future data evaluation.

The output of the total times for each task allowed the comparison of time required to time accomplished by task. This comparison identified incomplete service by task. The output of the aggregated times allowed a comparison of overall required service time to overall accomplished time. This provided total workload data for comparative analysis between user-selected mission profiles or equipment configurations. The specific techniques used to make the comparative analysis are explained in Chapter V.

SLAM summary reports at the end of each simulation run also provided useful output data. This summary contained the percentage utilization of the server, the number of times each task was sent to the queueing system and the total number of tasks that were released from service. These numbers were used in the verification of the model. A sample output listing is contained in Appendix B.

Specific Model Parameters

The task parameters used in the model are the result of examining the task, performing a literature search to estimate reasonable parameters and then using those parameters in the model. The impact of those parameters on the complete simulation was then evaluated and a sensitivity analysis was performed to determine the significance of the parameters. If the service of a task contributed more than 10 percent to the total service time it was considered significant. These tasks were then evaluated in more detail to determine the most accurate parameters possible. This process of parameter selection saved time by not wasting effort on noncritical parameter investigation and enhanced the value of the model by ensuring the accuracy of critical parameters.

The critical tasks identified in the process mentioned above for this model are the aircraft control task frequencies and service times and the threat reaction input parameters. The service times for the ECM tasks and the defensive maneuvers are significant, but are more easily defined than the aircraft control parameters. All task parameters are presented in the latter portion of this chapter with short discussions of all parameters except two types. A more extensive discussion of defensive reaction input parameters is presented at the end of this chapter, while flight control parameters are discussed in Chapter IV.

Task Priority Selection. All task service priorities are based on criticality of the task as it relates to the mission. Tasks that relate to aircraft control and mission survival are ranked highest, while activities associated with noncritical tasks like collecting information from an alternate source are ranked the lowest. Some tasks have the same priority for service but are preemptive because their immediate service is critical. For example, the ECM task priority is seven as is aircraft control, but an aircraft control task will preempt an ECM task. Aircraft control is a more urgent task because it involves a more immediate threat to life. The more critical ECM tasks that relate to immediate survival enter the system as defensive maneuvers. Defensive maneuvers include aircraft control and are therefore the highest priority task in the system and they are preemptive. The remainder of the system tasks are based on urgency and criticality and are listed in Table II.

TABLE II

TASK PRIORITY AND SERVICE SUMMARY

Task	Priority (Preemptive Y/N)	Mean (sec)	Standard Deviation (sec)
Defensive Maneuver	9(Y)	30.0	5.00
Turn to New Heading	8(Y)	18.0	9.00
Aircraft Control* (250)	7(Y)	1.426	1.289
(500)	7(Y)	1.612	1.629
(1000)	7(Y)	1.509	1.414
ECM** (Interpret RWR)	7(N)	.6	.20
(+ Dispense Decoy Material)	7(N)	1.7	.96
(+ Pod Setting Change)	7(N)	4.2	1.05
Change IFF	7(N)	6.6	.76
Fence Check	5(N)	20.5	7.50
Navigation Point Search	4(N)	6.0	1.50
Check INS	4(N)	3.0	.50
Check Next Heading	4(N)	1.8	.60
Change Fuel Switch	4(N)	1.1	.76
Update INS	3(N)	10.0	2.00
Turn Point Review	3(N)	6.0	1.50
Ops Check	3(N)	3.0	.50
Check Clock	3(N)	.6	.20
Crosscheck Heading/Course	3(N)	1.8	.60
Crosscheck Altitude	3(N)	1.8	.60
Crosscheck Speed	2(N)	1.8	.60
Check Fuel Status	2(N)	.6	.20
Crosscheck Compass System	1(N)	1.8	.60
Crosscheck Nav Leg Distance	1(N)	.6	.20

*The aircraft control mean and standard deviation vary with altitude.

**The ECM task service time is based on the level of threat.

Task Parameter Selection. Due to the nature of the service times for the tasks and the procedural repetition of tasks, the normal distribution was used to input varying parameters into the model. Specific task and initiation parameter selection is addressed below. All parameters are listed in units of seconds.

1. Navigation Leg Length

   $\mu = 420$

   $\sigma = 90$

   The desired leg length of seven minutes is based on the drift rate of the INS used in tests during Project Quick Look (Ref 1). This leg length is based on updating the INS at each turn point to maintain the required accuracy for the mission. The standard deviation specified allows for the variability of the distance between good navigation update points.

2. Navigation Search Repetition

   $\mu = 240$

   $\sigma = 15$

3. Crosschecks of HUD Displays With Cockpit Instruments for Altitude, Speed and Heading

   $\mu = 1.8$

   $\sigma = .6$

   These tasks require reading and interpreting the HUD and an instrument to confirm the HUD information. Parameters are based on the typical instrument interpretation times (Ref 11:15).

4. Crosscheck of INS Displayed Heading With Navigation Chart

$\mu = 1.8$

$\sigma = .6$

This task involves interpreting the HUD display or the course bearing pointer and comparing it to a printed symbol on a chart. The task is similar to other cross-check activities.

5. Navigation Point Search and Turn Point Review

$\mu = 6$

$\sigma = 1.5$

These tasks involve the use of navigation aids to confirm the aircraft position along the route. The variability is based on the range of difficulty of identifying some navigation cues.

6. Change IFF Setting

$\mu = 6.6$

$\sigma = .76$

This task involves the manipulation of as many as six toggle type switches on an IFF control head. The variability is based on the number of switches that would require manipulation.

7. Check Clock, Navigation Leg Distance and Fuel State

$\mu = .6$

$\sigma = .2$

These parameters are based on reading and interpreting an instrument or recorded symbol (Ref 11:15).

8. Crosscheck of Heading System With Magnetic Standby Compass

$\mu = 1.8$

$\sigma = .6$

This task confirms proper operation of aircraft compass systems with a standby magnetic compass. The cross-check is similar to crosschecks discussed earlier.

9. Update INS

$\mu = 10$

$\sigma = 2$

This task involves selecting predetermined geographic coordinates in the INS control head and initiation of a system update. The task time variability is based on the variation in INS error at each turn point.

10. Check INS Accuracy Between Updates

$\mu = 3$

$\sigma = .5$

This task involves estimating INS accuracy from navigation cues along the route when not approaching a turn point. The variability is based on the variation of INS error between check points.

11. Fuel Switch Manipulation

$\mu = 1.1$

$\sigma = .76$

This task involves a one time switch change for fuel sequencing such as external fuel tank deselection.

The parameters are based on typical toggle switch manipulation (Ref 10:15).

12. <u>Fence Check</u>

$\mu = 20.5$

$\sigma = 7.52$

This task is accomplished prior to FEBA penetration. The task includes preparing all defensive equipment for use and turning off all unnecessary emitting equipment to reduce passive detection by the enemy. The complete task requires the setting of two rotary switches and three toggle switches. The parameters are based on summing typical service times and standard deviations (Ref 11:15).

13. <u>Systems Operation Check (Ops Check)</u>

$\mu = 3$

$\sigma = .5$

This task involves the checking of aircraft support systems, engine instruments and the malfunction telelite panel. The variability is based on the number of items in the check.

14. <u>Aircraft Control Inputs and Service Times</u>

Between Inputs 250/500/1000 Feet		Service Time
$\mu = 1.631/1.746/1.514$	=	$1.509/1.612/1.462$
$\sigma = 1.692/1.716/1.490$	=	$1.414/1.629/1.289$

These are the sample parameters determined from empirical data. The process is fully explained in Chapter IV.

15. Turning to New Heading at Turn Points

$\mu = 18$

$\sigma = 9$

This task includes all aircraft control inputs while turning to a new navigation heading. The aircraft is assumed to use 45° of bank and turn at 2.5 degrees per second. The variability is based on turn of 0 to 90 degrees in 98 percent of all turns.

16. Defensive Maneuver

$\mu = 30$

$\sigma = 5$

This task involves maneuvering the aircraft to avoid an immediate threat and returning the aircraft to the desired navigation course. The maneuver length varies with threat type and terrain.

17. Electronic Countermeasures Task Service Time

μ	σ
.6*	.2*
1.7**	.96**
4.2***	1.05***

Three service times were required to accurately model ECM service. Each service time represents response to a different level of threat.

* RWR scope interpretation only.

** RWR scope interpretation and dispensing decoy material.

*** RWR scope interpretation, decoy material dispensing and ECM pod control panel switch changes.

Defensive Reaction Task Initiation Parameters. The defensive reaction tasks include ECM reactions and defensive maneuvers. The service times of these tasks are relatively straightforward because they involve easily definable activities. ECM task service is based on recognizing and interpreting a threat indication on a radar warning receiver (RWR) and selecting the action required to counter the threat. These reactions include merely noting the threat presence, the changing of a setting on an electronic countermeasure pod control panel, the dispensing of decoy material or any combination of the above to confuse the threat system. The defensive maneuver task is initiated by the same recognition and interpretation procedure or some external visual threat sighting. This task involves maneuvering the aircraft to avoid a projectile or evade the radar tracking system by terrain masking. Task service includes the time associated with returning to a desired navigation heading and altitude after defensive maneuver completion.

Service times for each defensive reaction task did not vary between mission profiles in the thesis. The frequency of tasking did vary between profiles. Defensive reaction task initiation was based on associating a threat rate with each leg of the mission. That is, each leg had a unique distribution for threat reactions. The threat rate was based on the first two mission legs being in friendly territory and the remaining legs in enemy territory.

The third leg of the mission included the FEBA penetration (see Figure 6). The same defensive reaction input distribution was used for respective legs of each profile except for the third leg. Defensive reaction input reduction with lower altitudes was modeled by not allowing all initiated tasks to reach the queue. The ratio of queued tasks to those initiated was developed by determining the ratios of threat reactions required at different altitudes using the threat array discussed below. A Monte Carlo technique using this ratio was then used to determine which tasks proceeded to the queue.

A defensive task initiation rate was also based on the results of a threat array investigation. The investigation used a model and array developed by Leek and Schmitt (Ref 4) for a course project in an advanced simulation course at the Air Force Institute of Technology. The array was developed from unclassified sources and was used to model the penetration of a Soviet Army on the Forward Edge of the Battle Area (FEBA) by a single aircraft. Figure 7 shows the threat array and flight corridor used to draw data. The model output gave the probability of kill (P_k) of a single aircraft for each weapon site in the array. These P_k's were based on radar detection and tracking equations using a representative aircraft cross-section and representative threat system capabilities.

The threat model was run twenty times for each of three altitudes to build a reasonable data base of P_k's.

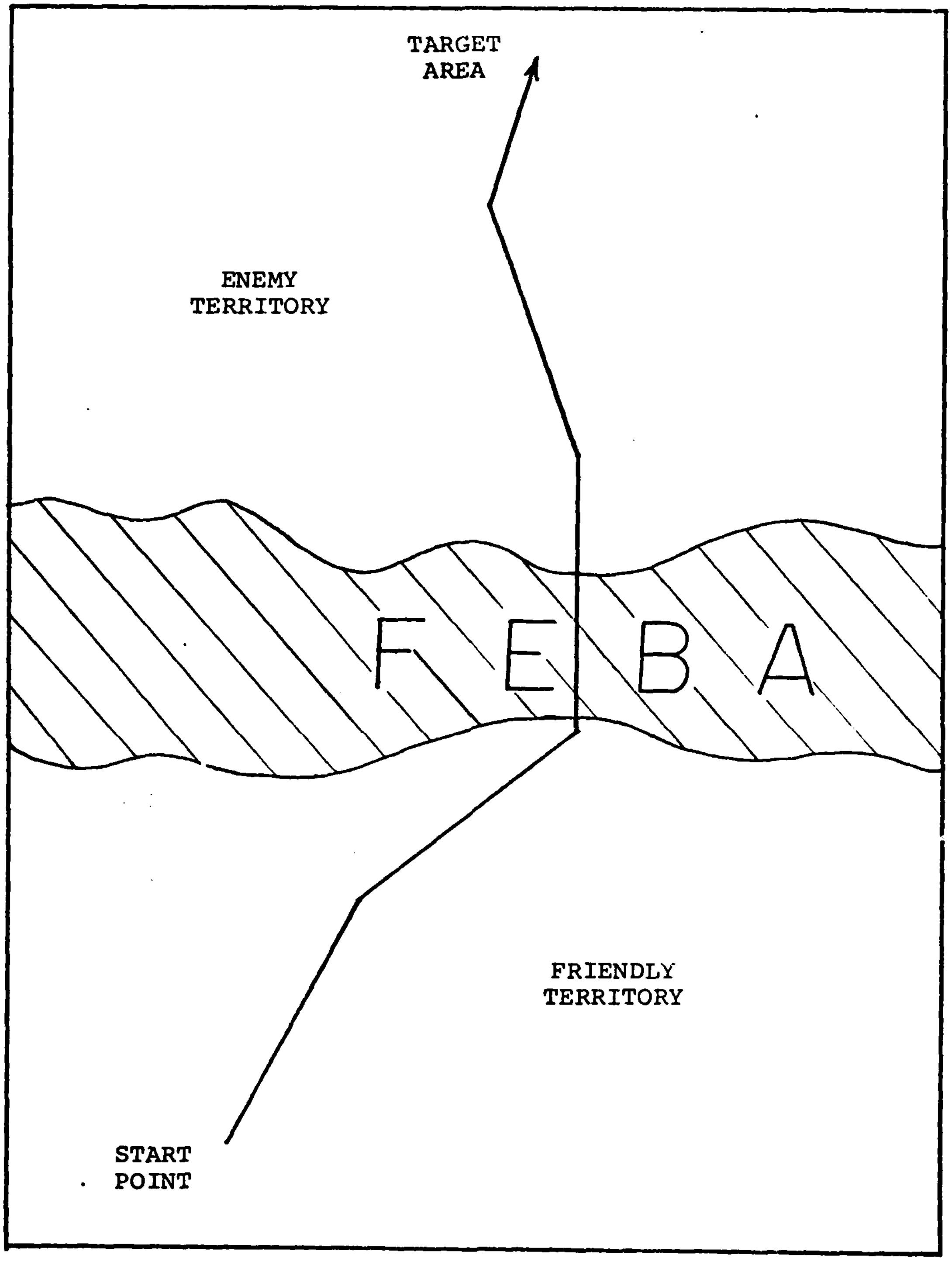

Fig. 6. Platform View of Mission Profile

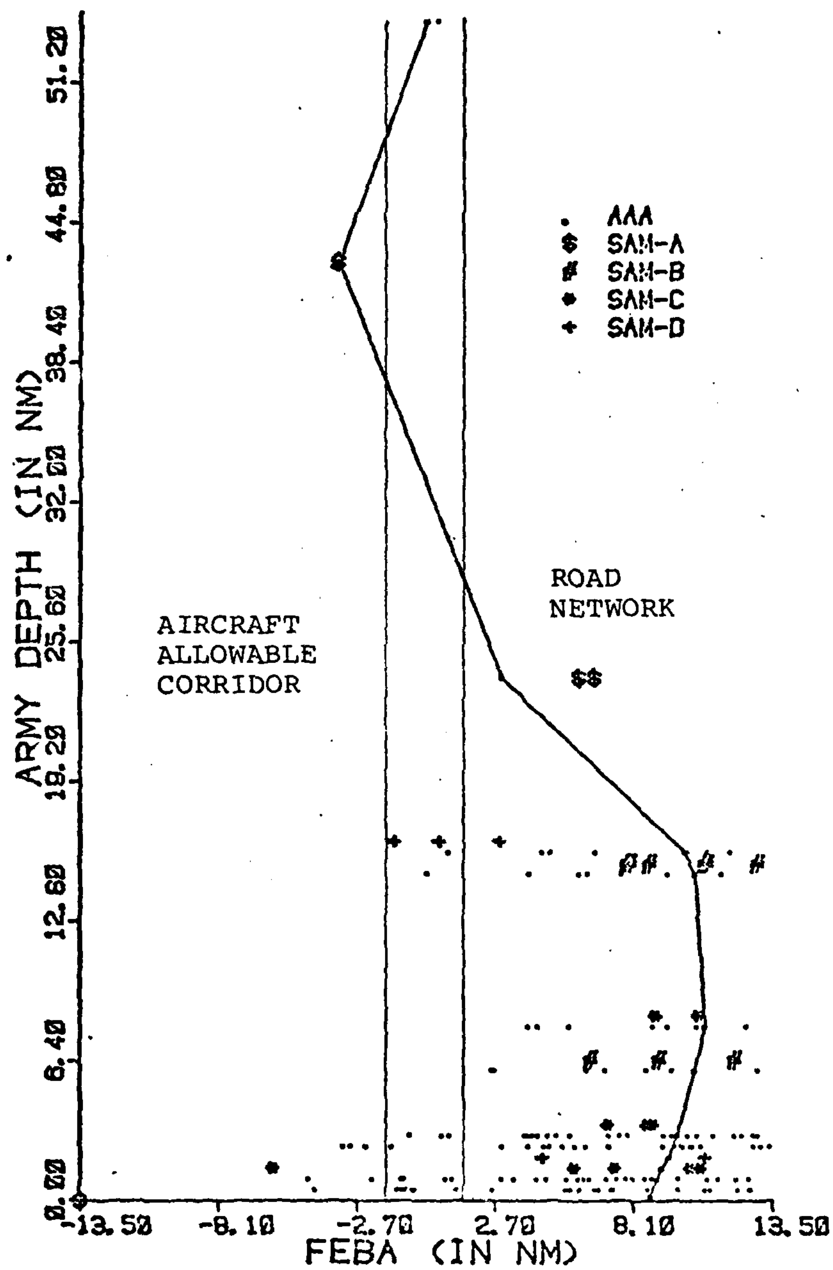

Fig. 7. FEBA Threat Array

The resulting P_k's were then examined to determine initiation rates of each type ECM task. If a threat P_k was greater than .01, it was accepted as an input into the system. This level of threat required an interpretation of the RWR scope as a minimum task. A P_k greater than .1 but less than .2 was assigned the task of dispensing decoy material and normal ECM pod operation (no pod control panel manipulation required) to confuse the threat radar system. P_k's greater than or equal to .2 but less than .3 required dispensing decoy material and changing the ECM pod setting. Defensive maneuvers were required for all P_k's greater than or equal to .3. The selection of .01, .1, .2 and .3 as task change points was a subjective decision based on the authors' operational experience in the ECM environment. A summary of the raw data from the threat array investigation is contained in Appendix D.

The time between threat reaction tasks and the number of tasks initiated was developed by examining the threat range limited by the aircraft altitude and the threat location in the FEBA array. The rate of encountering each threat system was determined by using a profile view of the FEBA array that depicted the threat locations and the system ranges (adjusted for aircraft altitude). The leading edge of each threat envelope was then marked and the distance between each leading edge was determined. Figure 8 shows a basic representation of this process for an aircraft at 1000 feet AGL. These distances were then

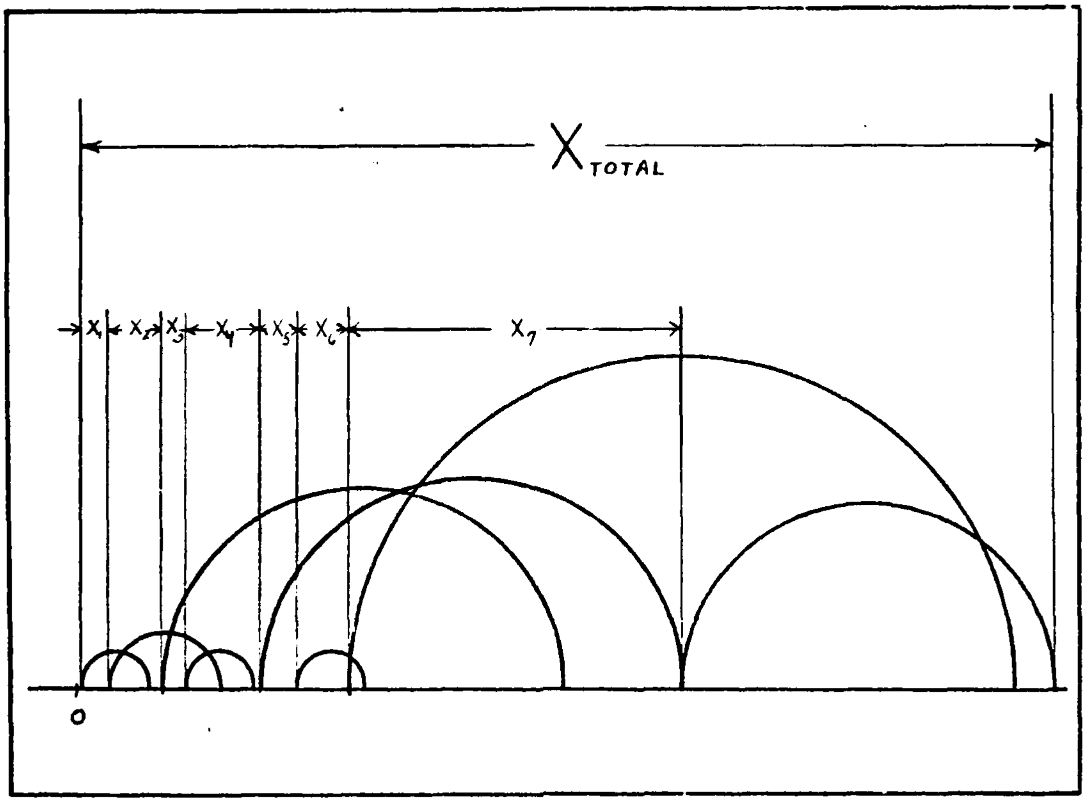

Fig. 8. Profile View of FEBA Array

transformed into time based on an aircraft speed of 360 knots. The resulting times were used to fit an exponential distribution for each altitude profile. The duration of the FEBA threat exposure (X_{total} in Figure 8) was determined by using the same figure to determine the time between entry into the first threat envelope and exit of the last envelope. This duration was used in the network model to terminate the high threat level associated with the FEBA. Table III is a summary of the input rates, durations and expected numbers of threats requiring inputs in the FEBA. An exponential distribution, with the parameters in Table III was used to input defensive reaction tasks.

TABLE III

FEBA THREAT INPUT PARAMETERS

Altitude (Feet AGL)	Input Rate	Duration (sec)	Expected Number *
1000	$\bar{x} = 20;\ s = 20$	210	10.5
500	$\bar{x} = 20;\ s = 20$	180	9.0
250	$\bar{x} = 12;\ s = 12$	90	7.5

*These expected numbers are the initiated tasks, not the queued tasks. Queued tasks at 500 feet = .68 x 9.0 = 6.32. Queued tasks at 250 feet = .33 x 7.5 = 2.5.

The shorter mean at 250 feet seemed unusual upon first examination, but further study indicated that it was reasonable. This was most easily shown by using a set of two diagrams of two different threat systems at each of two locations. Figure 9 graphically shows the effects of reduced threat range at lower altitudes. As Figure 9 shows, the mean time between threat envelope encounters was smaller at the lower altitude.

Model Computerization

The simulation language SLAM was used to computerize the model because it offered inherent network simulation structure and time sequencing of events. The SLAM language also allowed the use of subroutines written in FORTRAN for discrete event simulations and selection of output parameters and formats to suit the needs of the study. Although the continuous capability of SLAM was not

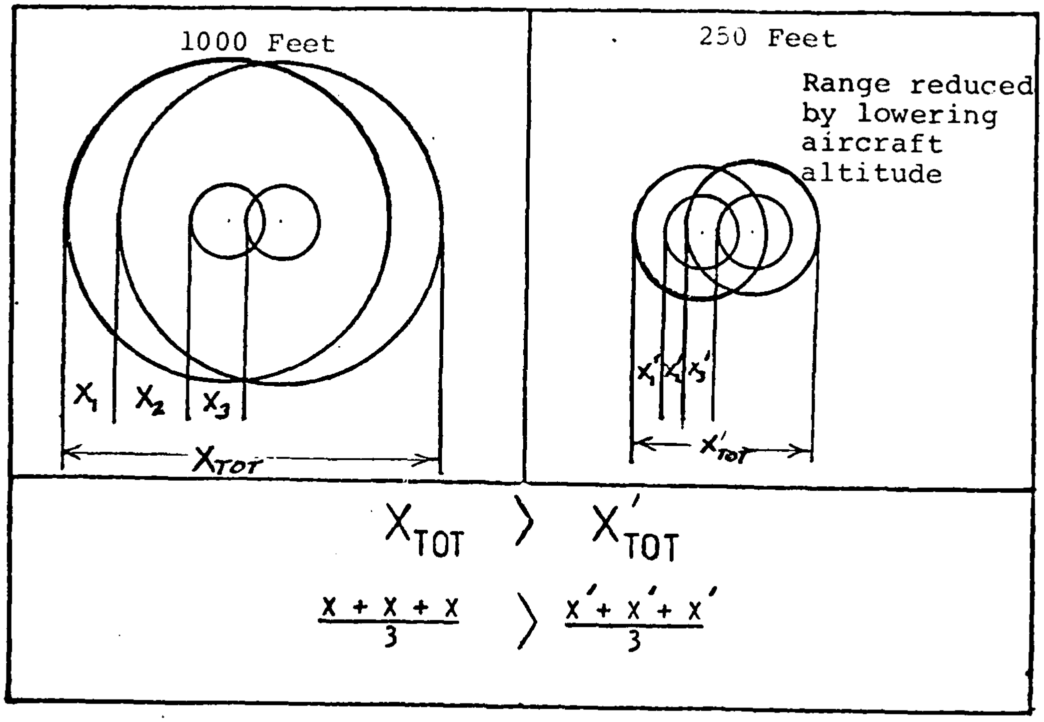

Fig. 9. Comparison of Threat Encounter Rates for Two Different Altitudes

used in this study the growth potential it provides for the model and this study are very desirable.

The network diagrams for the model and the flow charts for the subroutines are presented in Appendix A. The SLAM program coding is listed in Appendix B. Code documentation and explanations of coding steps are contained in the SLAM listing through the use of comment statements.

Model Validation

Model validation is the process of demonstrating that the model results duplicate the actual system results.

Since this model was designed to produce interval data for comparative purposes, validation was not a critical factor in this study. Validation methods that could be used are addressed next.

Direct physical validation of this model is impossible because the instrumentation required to document the real system could not be placed in a single cockpit aircraft. A less detailed validation could be accomplished by closely observing a pilot in a sophisticated simulator. The simulator mission could be patterned after a particular run of the model with the same leg lengths and threat inputs in order to give a comparable profile. The model results could then be compared with the simulator results. This less detailed validation would still be limited by the lack of risk associated with simulators and the lack of mission realism. Current tactical aircraft simulators lack the sophistication necessary to accomplish this validation. Face validity of the model is possible by examining the model output. The output is reasonable in the opinion of three tactical aviation pilots who examined the model results (Ref 3).

Model Verification

Model verification is the process of demonstrating that the model mechanically performs as designed. The process is necessary to establish confidence in the model results. Verification is especially important in this study since validation was not possible.

Model verification was accomplished in four steps. The first step involved the confirmation that the distributions used in the simulation provided the desired input data (Appendix C). The second step was tracing the operation of the model through one complete run to confirm proper mechanical operation of the model. The next step involved checking the model operation when limiting parameters were used as inputs. One run was made with all service times set equal to zero to confirm the resulting service time would be zero and no tasks would fail to be accomplished. A second run with all service times set at the mission length confirmed that no tasks were completed and the server was always occupied. Partial runs were also accomplished with parameters that allowed the confirmation of the stress scheme and the preempt capability of the model. The final verification step was the inclusion of checks in each run of the model that indicated which tasks if any were not being accomplished. This final step insured accurate data collection for each profile of the model.

The purpose of this chapter was to describe the model and the model parameters so a reader could establish confidence in the resulting data. This chapter should also provide a background for further studies in this area. The next chapter contains a description of the flight control parameter development process.

IV. Flight Control Movements

For this study the assumption was made that flight control movements were an integral part of pilot workload for a low-level navigation mission. Little research has been done on the subject. The lack of research on the technique of measuring pilot workload by interpreting flight control movements was, in part, due to the complexness of such an undertaking. A data base which would describe the expected frequency of movement of the flight controls for a given aircraft in every flight condition over all ranges of the aircraft's flight envelope would be an unnecessary if not an impossible task. However, for specified flight conditions, knowing the flight control movements required by an average pilot to fly a particular type aircraft over given terrain at specific altitudes would serve as a base from which to begin to measure pilot workload in a specified environment.

Basic control of an aircraft is accomplished by a pilot through manipulation of the primary aircraft controls; the stick, throttles, and rudder. All movements of an aircraft desired by a pilot are controlled by movements or combinations of movements of these controls. A data base which captures the distributions of periods of control movement and non-movement for an average pilot over a defined course in a specific aircraft would provide a foundation from which to study pilot workload from the viewpoint of pilot tasks.

No data base of flight control movements in the night low altitude environment existed in the form which was required for the technique of modeling proposed in this thesis. The A-10, LANTIRN simulator at the Wright-Patterson AFB Crew Station Design facility provided a source from which to gather the necessary data. With it, a data base was established which did describe the frequency of control movements and non-movements in a simulated electro-optical night environment.

The objective of the experiment was to obtain data from which frequency of flight control movements and non-movements could be developed. Four pilots were selected to fly the simulator. However, due to a malfunction in the data collection mechanism, data from the flights of the fourth pilot could not be used. The pilots had a fighter background with the experience shown in Table IV. They all had experience flying in the low-altitude environment. Although the pilots had previously flown the A-10 cockpit design simulator, none had done any actual flying for one year prior to the experiment. Prior to gathering data, each pilot was given 30 to 45 minutes to practice. At the end of the practice period all felt very comfortable controlling the simulator. The data was gathered while flying a route not flown during the practice session which

TABLE IV

PILOT EXPERIENCE

Pilot A	F-4 2100 hrs		T-38 125 hrs	
Pilot B	F-4 725 hrs	F-5 1250 hrs	T-38 1250 hrs	
Pilot C	EC-47 950 hrs	F-100 550 hrs	A-7D 1100 hrs	OV-10 400 hrs

consisted of combinations of flat and hilly terrain. The maximum tops of the hills were approximately 3000 feet above the surrounding terrain. The route contained five legs and four turn points (Figure 10). The lengths of the legs were 14, 12, 6, 7, and 27 nautical miles respectively. All turns were to the left and were 34°, 22°, 102°, and 62° respectively. The pilots maintained a constant power setting (full throttle) and the airspeed was allowed to vary between 350 and 450 knots depending on the rise and fall of the terrain. Power was kept constant and the airspeed was allowed to vary because time between turn points was not critical. In the actual combat environment pilots would be navigating with an inertial navigation system and following the directions it provided. Therefore, precise timing on the route was not necessary.

The simulator was equipped with a HUD similar to that which will be used on LANTRIN-equipped aircraft. A test pilot who had flown the simulator and aircraft

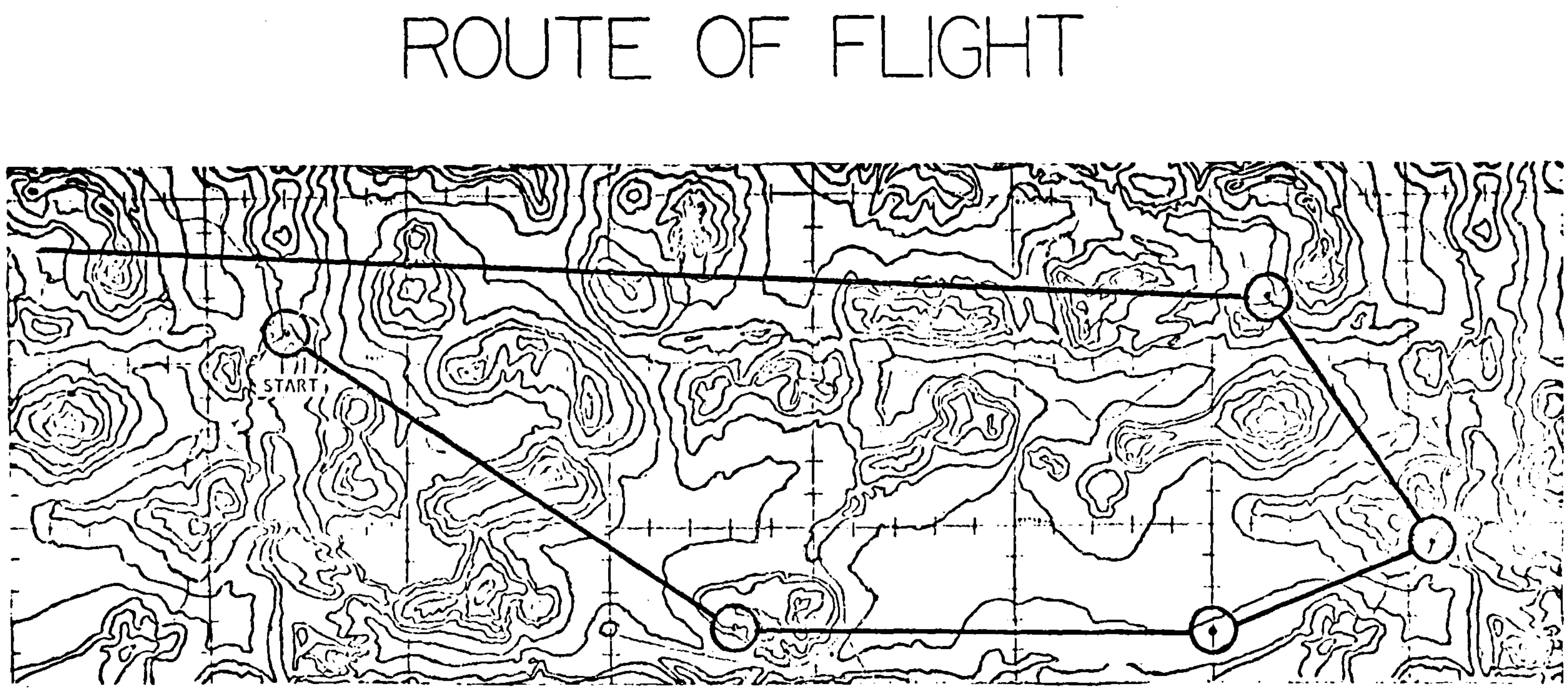

Fig. 10. Route of Flight

modified with forward looking infra-red (FLIR) displays, was quoted by the crew station design personnel as having said, "The visual presentation of the simulator closely approximated the real FLIR presentation."

The terrain forward of the aircraft was presented on the HUD. Cues were also presented on the HUD which indicated altitude above the terrain, airspeed, heading, and the pitch changes which were required to maintain the desired altitude above the terrain. Because the objective of the experiment was to determine the flight control movements necessary to fly the specified course, no extraneous tasks were presented to the pilots. The only mission each had was to fly the simulator by following the visual picture of the terrain and the cues presented to him on the HUD.

The data gathering runs were made while the pilots flew the course first at 1000 feet followed by 500 feet and 250 feet. Each mission required approximately ten minutes to complete. During each run, data was gathered at tenth of a second intervals. The data gathered were: (1) stick position in pitch and bank, (2) throttle position, (3) rudder position, (4) trim button position, (5) latitude and longitude, (6) altitude mean sea level, (7) altitude above the terrain, and (8) airspeed. All data was recorded on tape in a form compatible with a Control Data Corporation CDC 6600 computer.

Analysis

All data was reviewed for completeness by examining plots of runs and reading cross-sections of printouts of recorded data prior to analyzing it. In the analysis it was found that rudder and throttle movements were insignificant inputs in the control of the aircraft in this experiment. All pilots stated that throttles and the rudder were not moved. This was confirmed by observation of a cross-section of printouts from the data. Neither of these facts was a surprise; throttles were not moved because a constant power setting was briefed prior to the mission and rudders were not used because the type of maneuvering exhibited in the experiment did not require rudder coordination. The trim control was used very little; an average of eight to ten times based on the observed runs. The control inputs required to fly the aircraft on the specified profiles did not require an extensive number of trim control inputs. Trim control as an input to workload for this thesis was dropped from consideration for two reasons; it was used very little during the flights and trim was normally used in conjunction with control stick movements. Therefore, only the pitch and bank control movements were analyzed.

The definition of stick movement for this thesis was: a control stick movement forward or aft, left or right or any combination of forward or aft, and left or right movements. Stick position was recorded as a voltage.

Forward and aft movements were defined between +6.0 volts and -6.0 volts with + indicating the aft stick position. Left and right movements were indicated by voltages between +3.25 volts and -3.25 volts; + indicated a right movement of the stick. The position of the control stick was defined by voltages measured to .01 volts; however, noise in the system was ±.02 volts.

It was necessary to define movement in terms of the voltages so that a FORTRAN program (Appendix E) could be written and used to extract the data which described the movement and non-movement periods. Because noise was present in the system movement of the stick could not be accurately detected by looking for differences in each consecutive voltage. The noise gave erroneous indications of movement and biased the periods of movement and non-movement. To dampen the noise in the system, movement was determined by a stick position voltage being outside a base position. The base position was an interval of .04 volts in pitch and bank that defined where the stick position had to be if no movement of the control stick was to be recorded. A new base position was set each time each of the voltages over a period of six tenths of a second was less than the average of the six voltages ±.02 volts. The program individually checked the pitch and bank positions at each time period of one tenth second to determine if the stick was moving in pitch or bank. As an example, if the time was $T_{(now)}$, prior to checking the control stick bank position voltage, the program looked forward six tenths of a second and averaged the voltages.

$$V_{ave} = \frac{1}{6} \sum_{i=1}^{6} V_{[T_{now+i}]}$$

where

T_{now} = Time now;

V = Voltage; and

V_{ave} = Average Voltage.

If any of the voltage in the six tenth second interval was greater than V_{ave} ±.02 volts, the base was not reset. If all the voltages within the interval were within the interval of V_{ave} ±.02 the base was reset to the new interval. $V_{(T_{now})}$ was then compared to the base interval, if it was within the base interval the stick was not moving; if it was not within the interval the stick was moving. As mentioned earlier, if either the pitch or bank was moving the time period was classified as moving. Figure 11 shows two hypothetical base positions within the total movement area of the stick (not drawn to scale). It depicts more vividly the position the stick must be in for there to be no indications of movement; both pitch and bank voltages must be within the intervals which define the base "Box;" if either is outside the box the program senses a movement.

The interval of six tenths of a second was chosen as the period for establishing a new base because any time

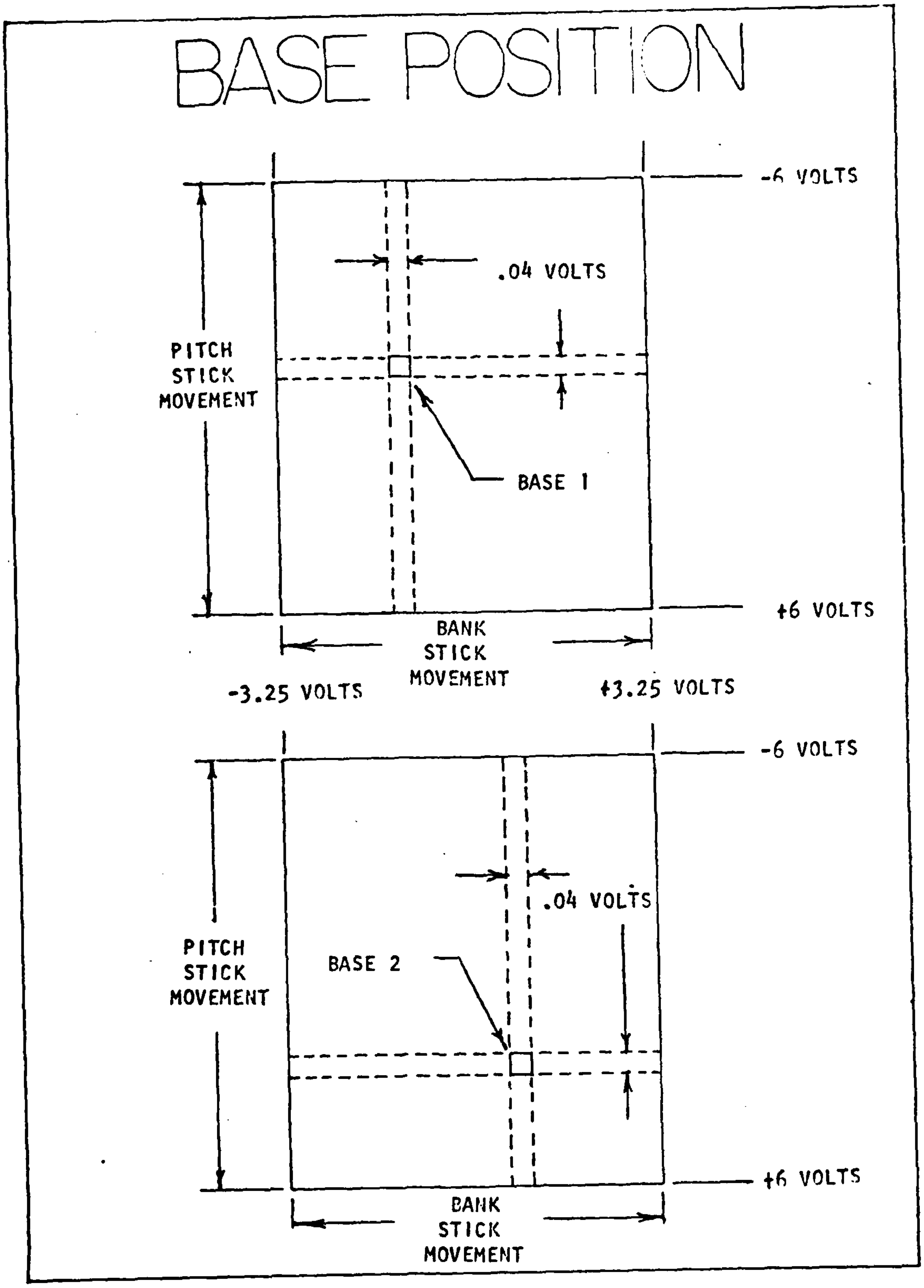

Fig. 11. Stick Movement Base Position

period less than that could mask a movement of the stick in noise; a smooth stick movement over a five tenth of a second time period could go from -.02 volts, through -.01, 00, +.01 to +.02 volts. The average of the five would be 0 and all voltages would be within the ±.02 volt interval. When the interval was extended to six tenths of a second the movement would either start from a position outside the interval or end in a position outside the interval and would not be classified as a movement.

As the program stepped through each time period it recorded the movements and non-movement periods. If a change was detected and confirmed the period of time of the condition prior to the change was recorded and a new interval was started. The program must have seen a trend of at least 3 tenths of a second before a change was recorded. If a trend for a change from movement to non-movement was noted and on the third sequential period the voltage indicated movement, the previous 2 tenths of a second period of non-movement was classified as noise and simply treated as a period of movement.

Any period of change less than three tenths of a second was treated as noise for two reasons: (1) no normal control movement or non-movement of two tenths of a second would have an effect on the movement of the aircraft, and (2) noise would cause frequent one and two tenths of a second excursions which would bias the distributions. The program was designed to sense the pulsing type stick movements that are encountered in this environment. Smooth movements such as the type a pilot would use in instrument flying would tend to be dampened. An example of this dampening is shown in the verification run (Appendix F).

Verification of the program was conducted with two lists of numbers, one for the pitch and one for the bank distribution direction (Appendix F). Each of the lists was voltages which defined known stick movements and rest periods for pitch and bank. The program was modified with print statements to track the course of the numbers in the program as each was tested. All changes of the pitch and bank bases were also tracked. The program detected and recorded the pre-selected distributions of movements and non-movements. To verify that the program could detect either pitch movements or bank movements, the pitch string of numbers was modified to remove one of the movements and the bank string was not changed. The program was run using the modified string; all stick movements were detected. The same modification was made on the bank string and the pitch string was not modified. The program was run and all movements were recorded which verified that the program did detect all movements and accurately recorded each.

Because only data from straight-line flight was desired, not all data that was recorded was used. Data recorded at turn points was not used to develop the distributions. Figure 12 depicts the blocks in which data was read and analyzed. With a few exceptions, only

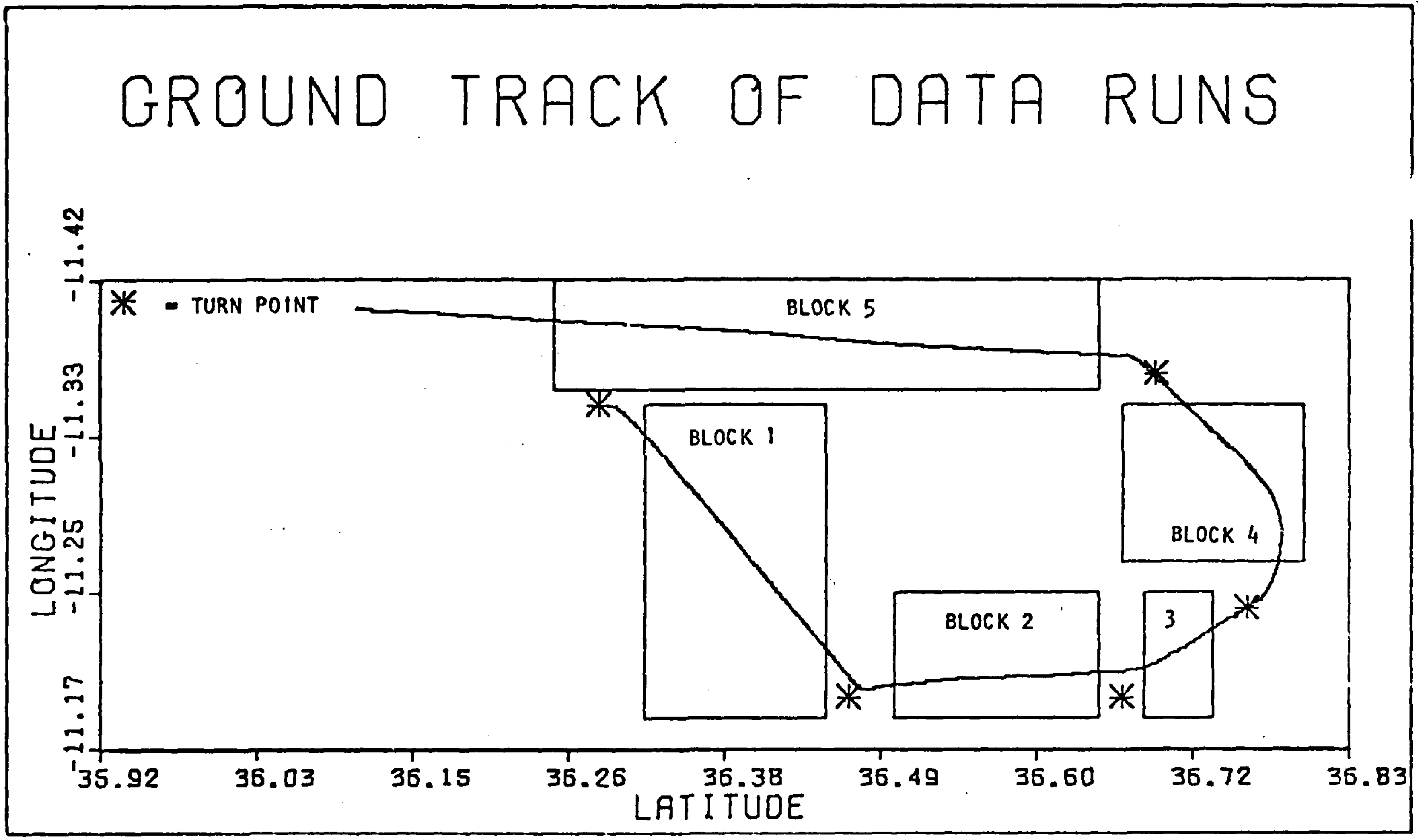

Fig. 12. Blocks where Data are Analyzed

straight-line flight was analyzed. Workload during the turns was treated as a separate function in the SLAM program. Therefore, including turns in the development of the distributions would have biased the overall analysis by double counting the work in the turns.

There were two sources of error in the program; neither significantly affected the distributions. The first occurred at the start of each run. The program allowed noise to enter during the development of the first time interval; it made no difference if the interval was a movement or a non-movement. It was probable that the program would begin in the middle of an interval of movement or non-movement. The result was the interval recorded would not reflect the true interval. Using the argument that the longest interval recorded during the experiment was 13.9 seconds and the average time of the recorded portion of each run was 4,700 seconds, the maximum probable error for the problem was less than .3 percent.

The second source of error was twofold. At the beginning of each run the base was assumed to be within the interval ±.02 volts; until the base was reset all voltages were compared with that base. Also, when the first voltage checked in a run indicated movement and the second voltage checked indicated no movement, the first was recorded as a period of one tenth of a second of movement. This also was not significant and produced errors of no more than .02 percent.

Results

Table V depicts the statistical results of each run. Appendix G contains the histograms for all runs. Each distribution had large standard deviations caused by a few large excursions in movements and non-movements. The excursions were due to the non-homogeneous terrain over which the data was collected. The sample distributions did not appear to be from any published distribution. A basic attempt to curve fit a few of the distributions to gammas and exponentials was made; however, because of the lack of success to curve fit the distributions and the fact that empirical data was satisfactory for input to the low-level navigation model no curve fitting was done.

The Friedman two-way ANOVA by ranks test (Ref 12: 166) and the Kolmogorov-Smirnov two-sample test (Ref 12: 127) were used to determine the probability that related distributions were from the same population. Because the Friedman two-way ANOVA was quite robust, the Kolmogorov-Smirnov test was used to confirm the results of the Freidman test.

Four Friedman tests were performed; two for movements and two for non-movements. The first tested whether or not the mean movements for a pilot at all altitudes were from the same population as the mean movements of the other pilots at all altitudes. Table VI shows the arrangement for the test.

TABLE V

PILOT STATISTICS

	Stick Movements		No Stick Movements	
1000 FEET				
	Mean	Std Dev	Mean	Std Dev
Pilot A	1.327 sec	1.403 sec	1.676 sec	1.881 sec
Pilot B	1.559 sec	1.544 sec	1.556 sec	1.620 sec
Pilot C	1.655 sec	1.253 sec	1.665 sec	1.551 sec
600 FEET				
	Mean	Std Dev	Mean	Std Dev
Pilot A	1.081 sec	1.030 sec	2.077 sec	1.967 sec
Pilot B	2.126 sec	2.137 sec	1.717 sec	1.768 sec
Pilot C	1.680 sec	1.403 sec	1.413 sec	1.246 sec
250 FEET				
	Mean	Std Dev	Mean	Std Dev
Pilot A	1.137 sec	9.888 sec	1.605 sec	1.571 sec
Pilot B	1.764 sec	1.524 sec	1.211 sec	1.119 sec
Pilot C	1.398 sec	1.245 sec	1.721 sec	1.674 sec

TABLE VI

FRIEDMAN TWO-WAY ANOVA BY RANKS; ALTITUDE

	Pilot 1	Pilot 2	Pilot 3
ALT 1000	1.327	1.559	1.655
ALT 500	1.081	2.126	1.680
ALT 250	1.137	1.763	1.398

The Friedman Test tested H_0: that all columns were from the same population. The results showed that there was a probability of .194 that the columns of means came from the same population. The Friedman test was used to test the non-movement means in the same manner. The probability that H_0: the columns of means of non-movements were from the same population, was true was .361. Both indicated that there was a low probability that the distributions of the means of each pilot were from the same population as the other pilots. Table VII shows the arrangement which was used to test if the means of the movements of pilots at each altitude were from the same population.

TABLE VII

FRIEDMAN TWO-WAY ANOVA BY RANKS; PILOT

	1000 FT	500 FT	250 FT
Pilot 1	1.327	1.081	1.137
Pilot 2	1.559	2.126	1.764
Pilot 3	1.655	1.680	1.398

The test indicated H_0: the means of the distributions of movements of pilots at each altitude were from the same population, was true with a probability of .944. Testing the non-movements using H_0: the means of the distributions of non-movements of pilots at each altitude were from the same population, indicated that the probability that H_0 was true was also .944. Because the Friedman test is very robust and little is known about the power of the test, more statistical comparisons of the distributions were made using K-S two-sample tests. The K-S two-sample test was used to test the null hypothesis that the two distributions being tested were from the same population. The two-tailed probability that H_0 was true was recorded for all the combinations of movement distributions between pilots at each altitude and then between altitudes for each pilot. The same tests were conducted using the non-movement distributions. See Appendix H for the results of the test.

The results indicate that there are greater probabilities of distributions being from the same population for a pilot at the three different altitudes than between pilots at the same altitude. Figures 13 through 17 show this more graphically. Little difference can be seen between the pitch and bank movements as Pilot A changes altitudes. However, a definite difference can be seen between Pilots A, B, and C at 1000 feet. The unexpected finding indicated there was little difference in pilot workload due

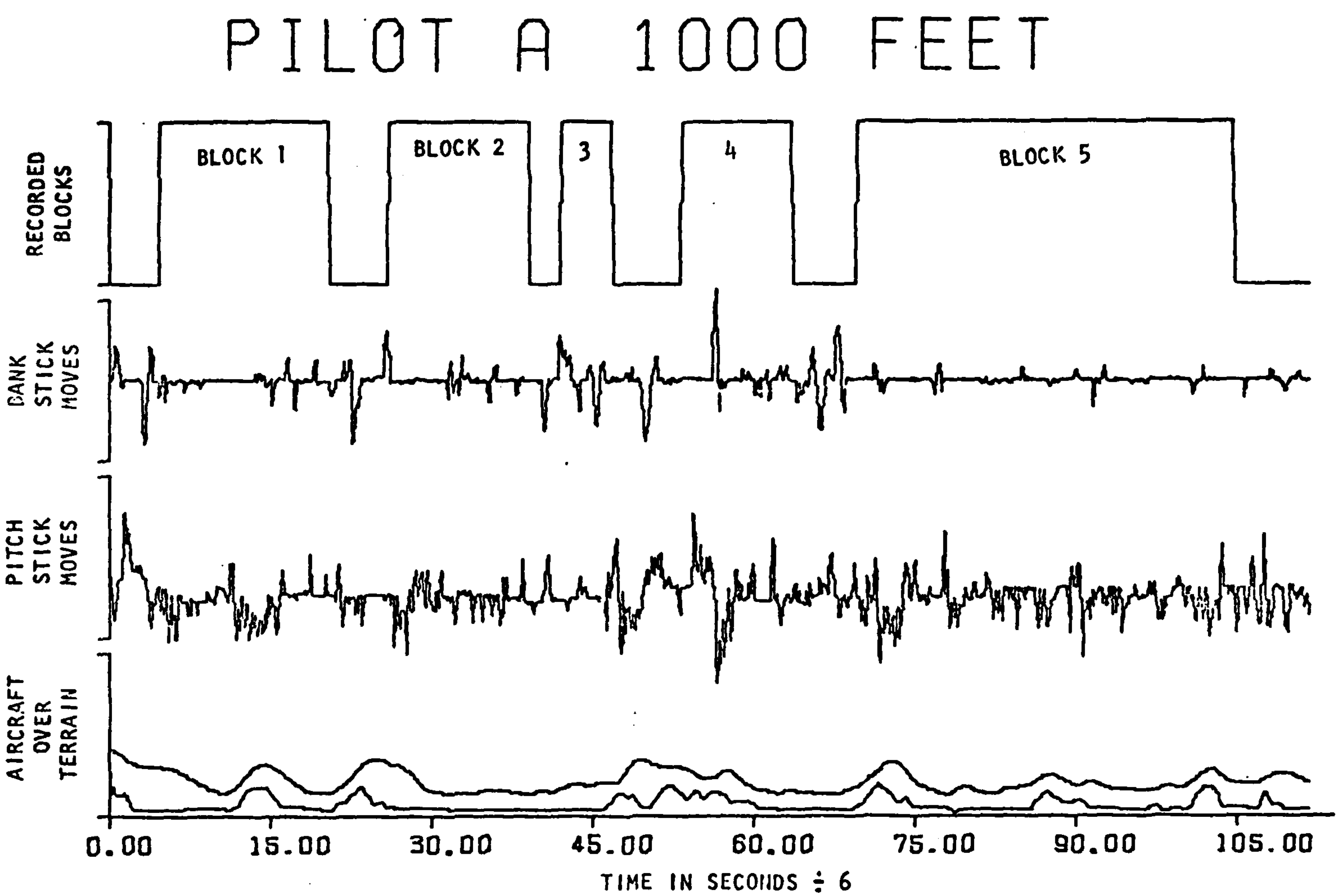

Fig. 13. Profile of Pilot A, 1000 Feet

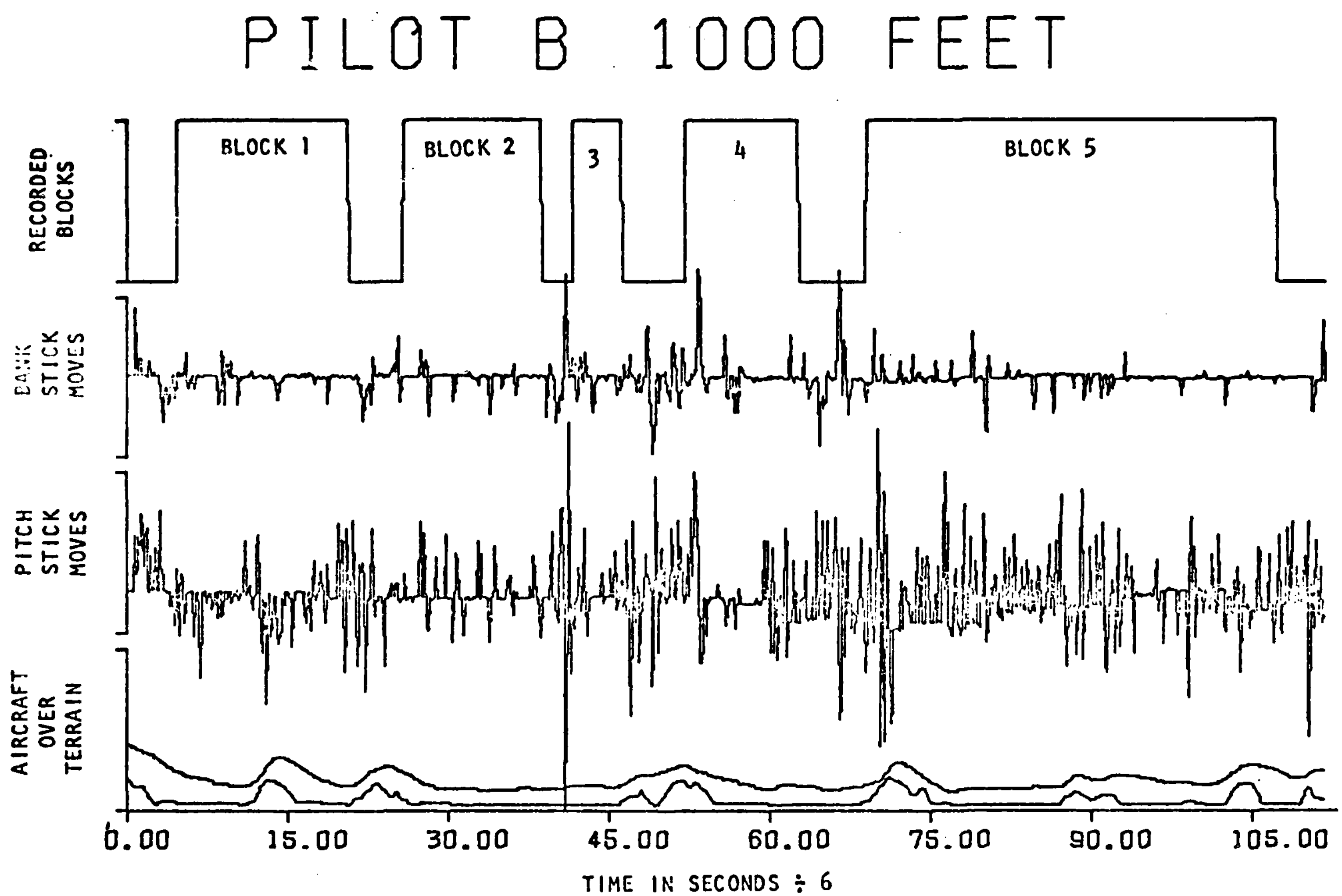

Fig. 14. Profile of Pilot B, 1000 Feet

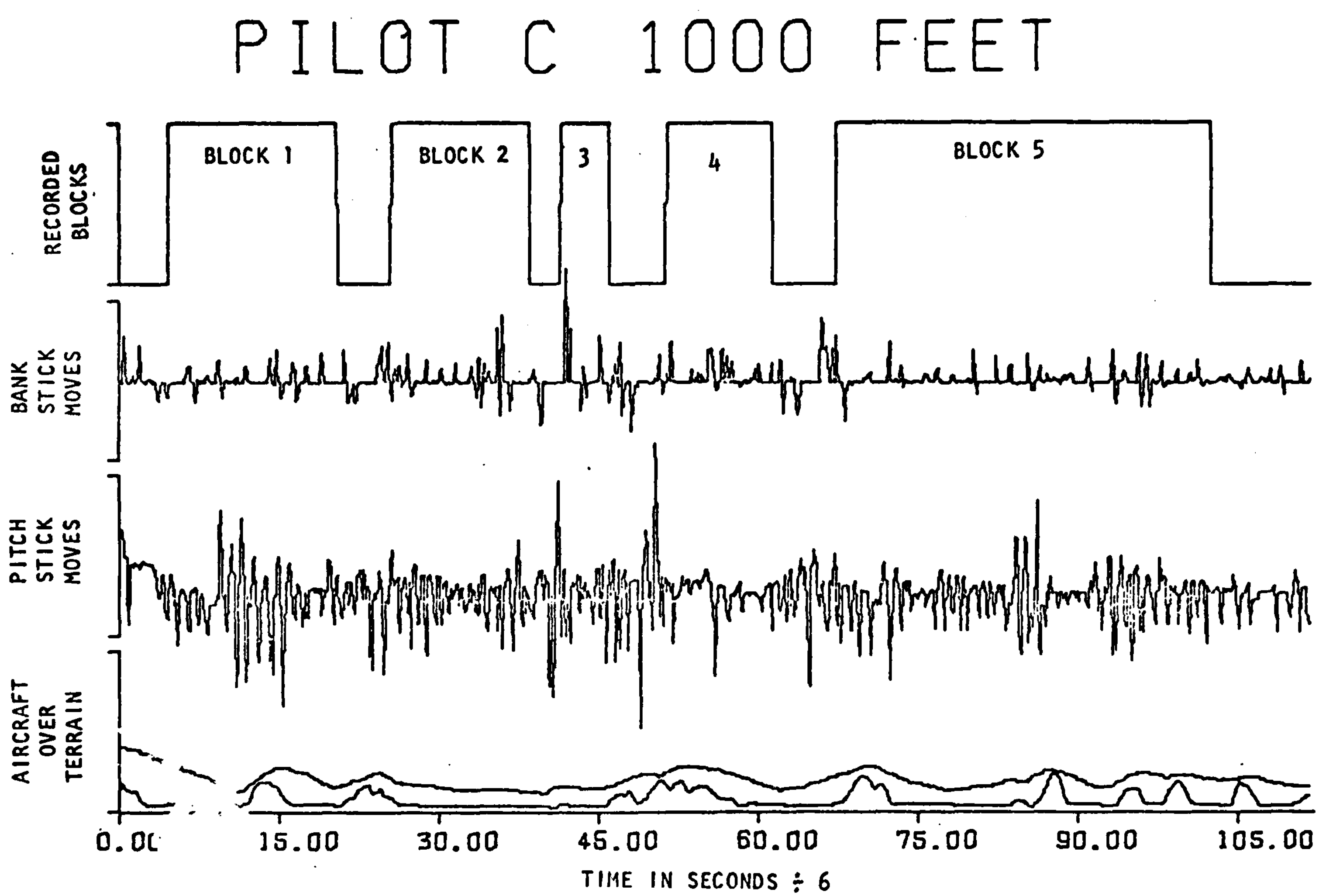

Fig. 15. Profile of Pilot C, 1000 Feet

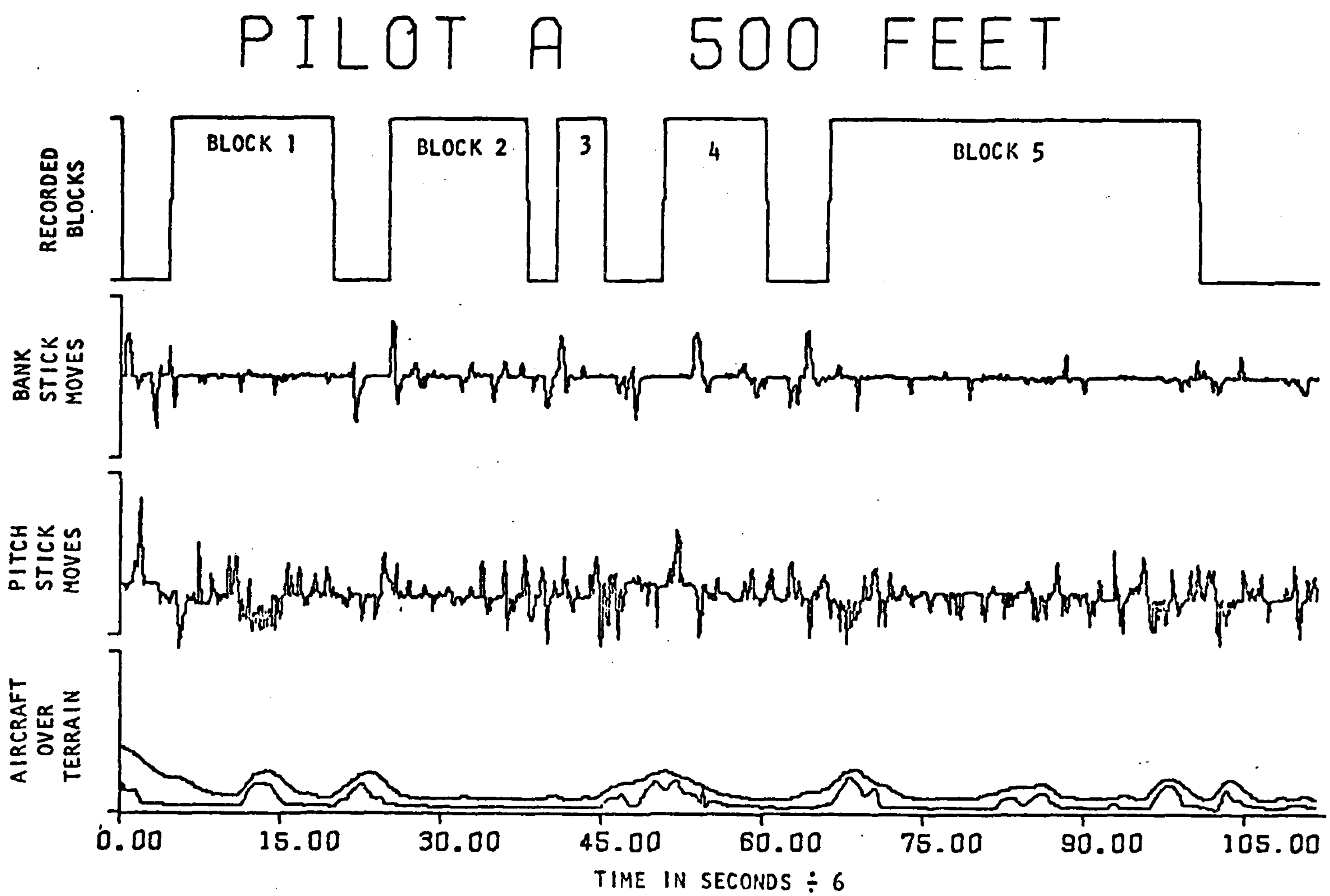

Fig. 16. Profile of Pilot A, 500 Feet

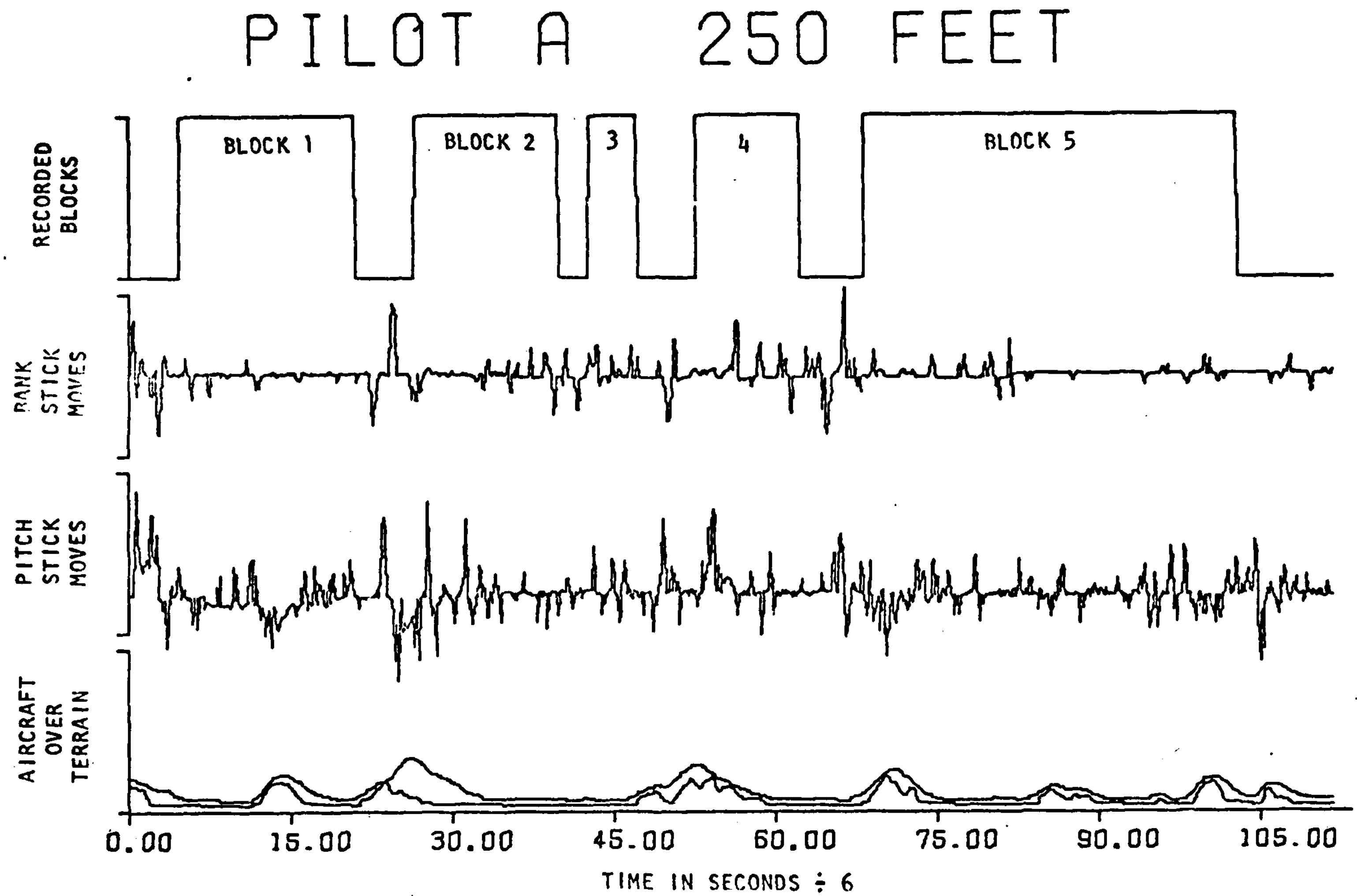

Fig. 17. Profile of Pilot A, 250 Feet

to movement of flight controls for the low-level flights in the three altitude blocks.

It appears the reason for the lack of difference between flight control movements at the various altitudes is twofold. The amount of vertical movement of the aircraft was similar for each altitude block. Because the terrain over which the route was flown was quite flat between hills, flying at a lower altitude did not increase the number of hills that affected the flight path of the aircraft. Or, stated another way, the three-thousand-foot hills or mountains had very close to the same affect on the required vertical movement of an aircraft at 1000 feet AGL as they had on an aircraft at 250 feet AGL. The second factor was that the pilots were following a pitch director which gave indications when to raise and lower the nose of the aircraft to avoid the terrain by the specified amount. The cues tended to dampen the effects of the terrain by starting pitch changes in approximately the same locations prior to the hills.

Further study was done to confirm the aircraft altitudes for each run. This was necessary to show that the aircraft were at the specified altitudes. All were within the specified altitudes for the majority of the time on each run. Table VIII indicates the amount of time that was spent in various altitude bands for each run. It also shows that the aircraft on each run was at the altitude specified for the majority of time.

TABLE VIII

ALTITUDE (AGL) FOR EACH RECORDED PORTION OF A RUN

	TENTHS OF SECONDS		
	1000 FEET	500 FEET	250 FEET
PILOT A			
Less than 150 feet	0	1	6
150 feet to 350 feet	0	11	1972
351 feet to 650 feet	0	2409	1878
651 feet to 1350 feet	2879	2001	623
Greater than 1350 feet	1878	174	224
200 feet to 300 feet	0	0	965
450 feet to 550 feet	0	935	532
950 feet to 1050 feet	737	226	73
PILOT B			
Less than 150 feet	0	0	171
150 feet to 350 feet	0	122	1804
351 feet to 650 feet	80	2258	1948
651 feet to 1350 feet	3477	2013	772
Greater than 1350 feet	1375	287	32
200 feet to 300 feet	0	70	1095
450 feet to 550 feet	38	1022	542
950 feet to 1050 feet	698	247	105
PILOT C			
Less than 150 feet	25	22	60
150 feet to 350 feet	71	126	1616
351 feet to 650 feet	179	1677	1864
651 feet to 1350 feet	2785	2462	1070
Greater than 1350 feet	1648	329	301
200 feet to 300 feet	34	79	998
450 feet to 550 feet	50	755	531
950 feet to 1050 feet	625	325	86

As mentioned earlier, the objective of the experiment was to develop distributions of movement and non-movement of flight controls for the low-level navigation model. Figures 18 through 20 show the average distributions which were developed by combining the data from all three pilots at each altitude. Each depicts the cumulative distribution and the probability density function for stick movements and non-movements at each altitude. How they were used was described in Chapter III. The statistical data for the distributions is in Table IX.

It must be remembered that the distributions were developed from a simulated flight. The pilots used in the experiment were not proficient in low-level navigation although they had many hours of experience in the low-level environment. Both these points raise questions about the validity of using the distributions to predict pilot workload. To dampen this argument one point must be mentioned--the distributions that were developed were the combined distributions of stick movement that were used by three pilots to safely fly the simulator at the specified altitudes. Therefore, it can be said that in using the distributions as indicators of workload in the way this thesis uses them, prediction of pilot workloads can be made for the simulated environment. Further study is required using [illegible] methods of measuring controls stick movements. [illegible], in part, measured by movement of

TABLE IX

AVERAGE PILOT STATISTICS

	Stick Movements		No Stick Movements	
	Mean	Std Dev	Mean	Std Dev
1000 FEET	1.509 sec	1.414 sec	1.631 sec	1.692 sec
500 FEET	1.612 sec	1.629 sec	1.746 sec	1.716 sec
250 FEET	1.426 sec	1.289 sec	1.514 sec	1.490 sec

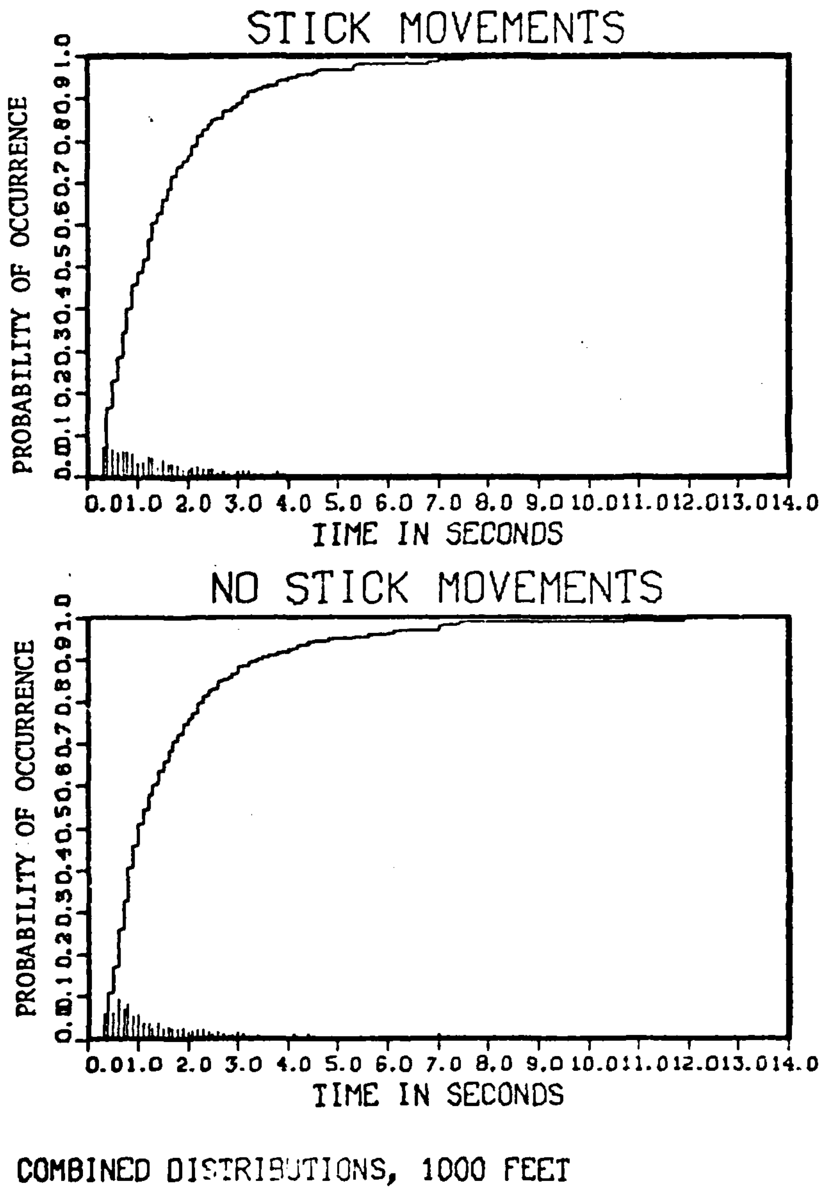

Fig. 18. Combined Distributions for Pilots at 1000 Feet

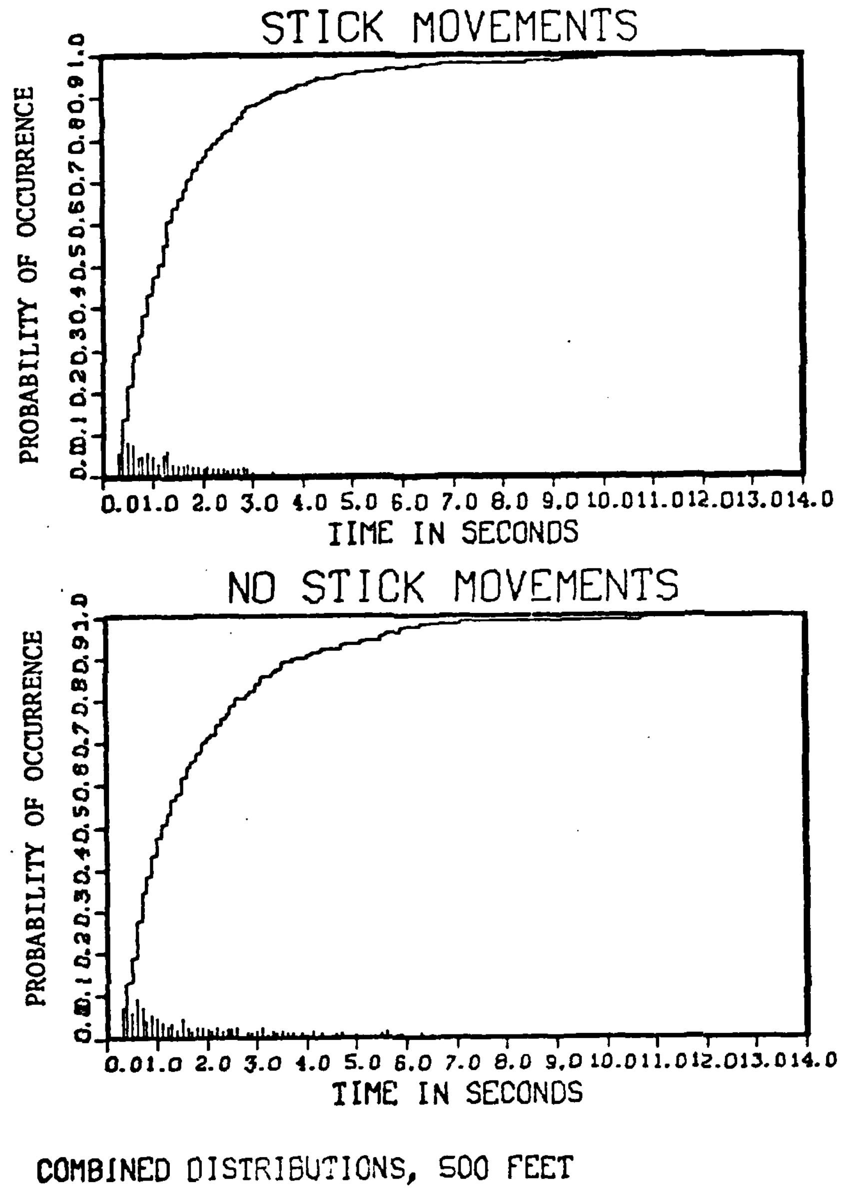

Fig. 19. Combined Distributions for Pilots at 500 Feet

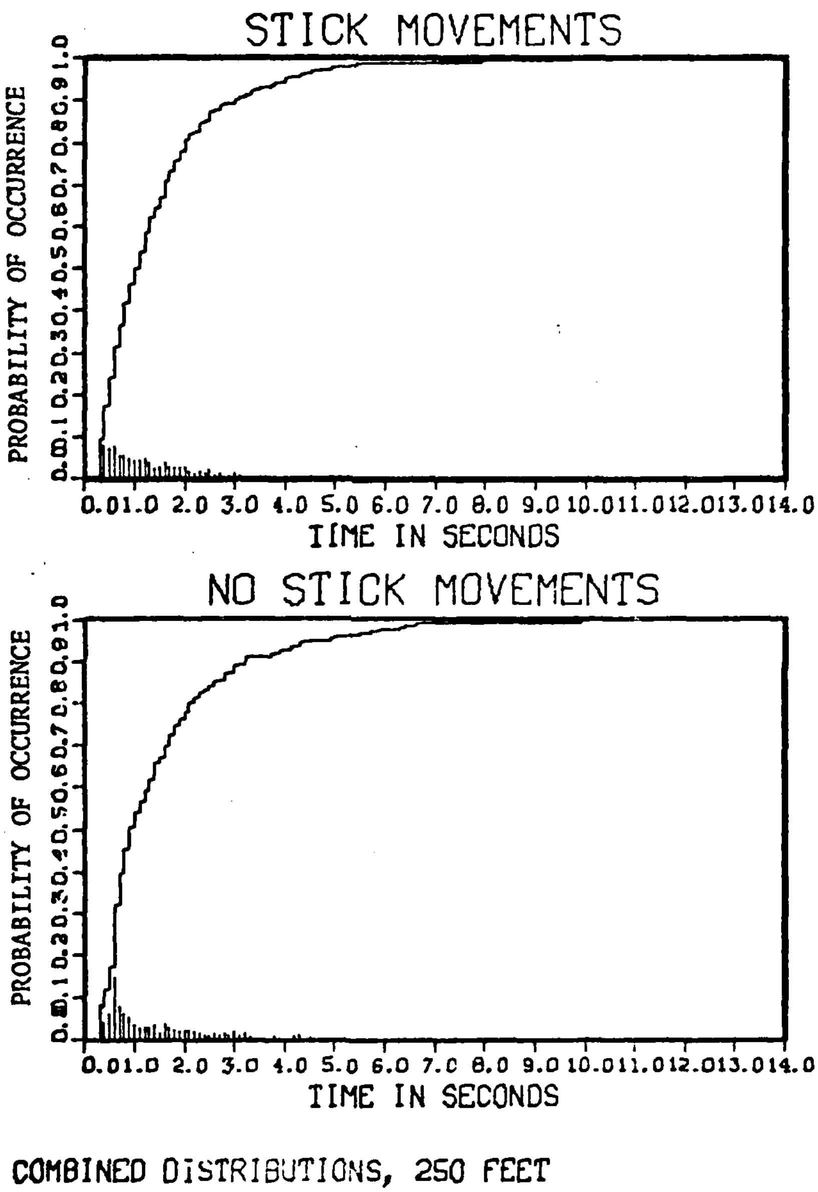

Fig. 20. Combined Distribution for Pilots at 250 Feet

flight controls. Not only the frequency but the amount of actual stick travel in each movement must be studied.

After the stick movement and non-movement distributions were developed, data was gathered via the SLAM program for the analysis of pilot workload.

V. Data Collection

Presented in this chapter are the measure of merit and experimental design used in this study. Model modification for different profiles, replication requirement determination and the employed variance reduction technique are also discussed.

Measure of Merit

A measure of merit is a yardstick for measuring experimental results. In the case of simulation experiments, this measure is often specifically designed for that study. The measure of merit for this study was based on an adjustment of the number of seconds the pilot was busy servicing tasks in an 1800 second mission. The adjustment was accomplished by computing the difference between the number of seconds the pilot was busy and the number of required service seconds. This difference was then doubled and added to the service time accomplished.

$$\text{Mom} = S + 2(R-S)$$

Mom = Measure of merit

S = Serviced

R = Required

The difference between required task time and accomplished task time was doubled to emphasize the failure of all tasks to be completed. Simply measuring the required task time for each profile would not indicate the existence of high workload density in portions of the system. This concept was based on the idea that a more evenly distributed workload that allows completion of all tasks is preferable to a system with overtasked periods that prevent completion of every task.

Experimental Design

An experimental design is a plan for the orderly collection of data to be analyzed. The design consists of the selection of the experiment factors (variables) and the different values the factors are allowed to assume. A full factorial experiment is one that collects data on all combinations of factors and factor levels. The experiment design used for this study was a full factorial design with two factors at three levels. The design was based on providing data to allow an analysis of variance procedure on proposed mission profiles and service variation. This design required nine cells of data with sufficient replications in each cell to provide the desired accuracy of the sample mean of each cell. The nine cells represented all the possible configurations of the two factors with three different levels of each factor. The full factorial design is depicted in Figure 21.

Model Modification

Data collection required model parameter modification to simulate the nine profiles compared in this study.

		ECM TASK LEVEL		
		0	1	2
ALTITUDE	250	1	2	3
	500	4	5	6
	1000	7	8	9

Fig. 21. Full Factorial Experimental Design

ECM Task Levels

0 - No action required by the pilot.

1 - Only required action was to note threat presence--no equipment manipulation required.

2 - No ECM equipment automation--full service as specified in Chapter III.

Altitude Level (Feet AGL)

1 - 250

2 - 500

3 - 1000

The parameter adjustments for each of the three altitudes selected involved changing the discrete empirical aircraft control distribution developed for each altitude. The required modification for the ECM changes involved changing both task initiation parameters and service parameters. The ECM task initiation parameters changed with each altitude as described in Chapter III. The ECM service parameters were altered for each of the three levels of service described in Chapter III by setting the service time equal to either zero, reduced time allowed by a fictitious automated threat reaction system that required RWR scope interpretation only, or the full service time required for manual threat interpretation and reaction.

Experiment Replications

The number of replications for each cell of the experimental design was determined by running a pilot experiment of ten replications. The results of this pilot run were used to approximate the required number of replications as shown in Shannon (Ref 10:186).

$$n = \frac{t^2 s^2}{d^2}$$

where,

- n = number of necessary replications;
- t = tabulated t value for the desired confidence level and degrees of freedom of the initial sample;

s^2 = the estimate of the variance obtained in the pilot run; and

d = the half-width of the desired confidence interval.

On the pilot run with five replications, $s^2 = (43.47)^2$, $t = 2.23$ and d was selected to be 30 seconds. The resulting required replications were:

$$n = \frac{(2.23)^2 (43.47^2)}{(30)^2} = 10.33$$

Therefore, eleven replications per cell were planned to achieve the desired accuracy.

Variance Reduction

In order to increase the efficiency of the model, a variance reduction technique was employed to reduce the number of model runs required to achieve the desired output accuracy. The pilot sample as well as all experiment replication were obtained using the antithetic variance reduction technique. In the SLAM language this was accomplished by using a positive seed in the random number generator for half the experiment replications and using the negative of the same seed for the remaining replications in each cell. When this variance reduction technique is used, the raw data must be transformed into a new statistic by using the following equation (Ref 8:385).

$$U_i = \frac{x_{i+} + x_{i-}}{2}$$

where,

U_i = the new test statistic;

x_{i+} = the value determined using a positive seed; and

x_{i-} = the value determined using a negative seed.

The resulting sample size used in the analysis of variance (ANOVA) procedure is smaller but the variance is significantly reduced. For example, after the model was run for 22 replications (11 with a positive seed and 11 with a negative seed), the raw data variance was $(61.74)^2$ and the variance of the transformed data was $(28.41)^2$.

After having run 198 replications of the model to obtain 99 data points (11 for each cell), the data collection was complete and data analysis began. The results of the data collection process are shown in Figure 22.

ALTITUDE		ECM TASK LEVEL		
		0	1	2
	2500	1194	1205	1204
	5000	1185	1197	1218
	10000	1293	1314	1324

Fig. 22. Data Collection Results

VI. Data Analysis

In order to demonstrate the usefulness of the model in studying pilot workload, the data gathered in Chapter V was grouped into nine cells of eleven data points. The mean (shown in Figure 22) and the variance of the measure of merit for each cell was compared in the data analysis process. This comparison allowed the grouping of cells that were statistically the same on a 95 percent confidence level, $\alpha = .05$. The analysis also identified statistically differing cells.

Data analysis was accomplished in two phases. The first phase was the use of a two-way ANOVA procedure using the Statistical Package for Social Sciences (SPSS) (Ref 6:399) to study the effects of the main factors and any possible interactions between the factors. The SPSS output is listed in Appendix I. The second phase was a one-way ANOVA procedure using SPSS to compare the means of each of the nine profiles. Each profile was considered a treatment and a Duncan Multiple Range Test was used to rank the means of the measure of merit of each profile. This SPSS output is also listed in Appendix I.

Two-Way ANOVA

The two-way analysis of variance procedure was used to investigate the effects of each main factor (altitude

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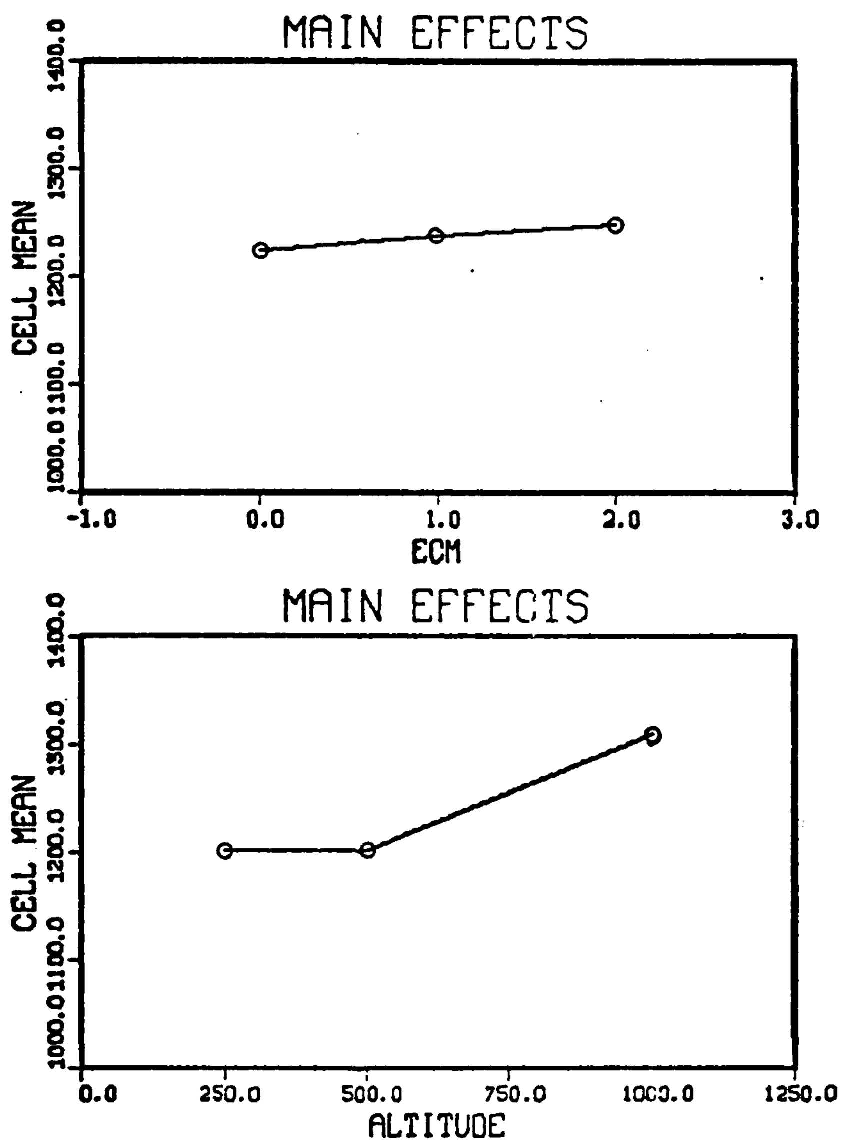

Fig. 23. Main Effects Graph

and ECM service time) and the interaction effect of the two factors. Based on a 95 percent confidence level, only the effect due to altitude change was statistically significant. The analysis of variance table in Appendix I shows the degree of significance of each effect.

The main effects as a group were significant. This was a result of the strength of the altitude change effect and the near significance of the ECM service time effect. The ECM service time would have been significant at a 92 percent confidence level. Figure 23 shows the trend of workload with each main effect. This figure shows a slight increase in pilot workload (ordinate) as ECM service time (abscissa) is increased. This was anticipated and seemed intuitively obvious. Figure 23 also shows an increase in workload as altitude was increased. This was not anticipated when this thesis was undertaken, but after the results of the investigation of flight control parameters were examined, it too could be understood. The underlying cause of this increase was due to the increase in defensive reaction rquirements at higher altitude. The more significant increase from 500 feet to 1000 feet was a result of the defensive maneuver requirements.

The interaction effect of the change of both factors simultaneously was very insignificant. This was indicated in the ANOVA table (Appendix J) and confirmed by the parallel trends of the lines in Figure 24. This result was reasonable because the magnitude of the increase due to the

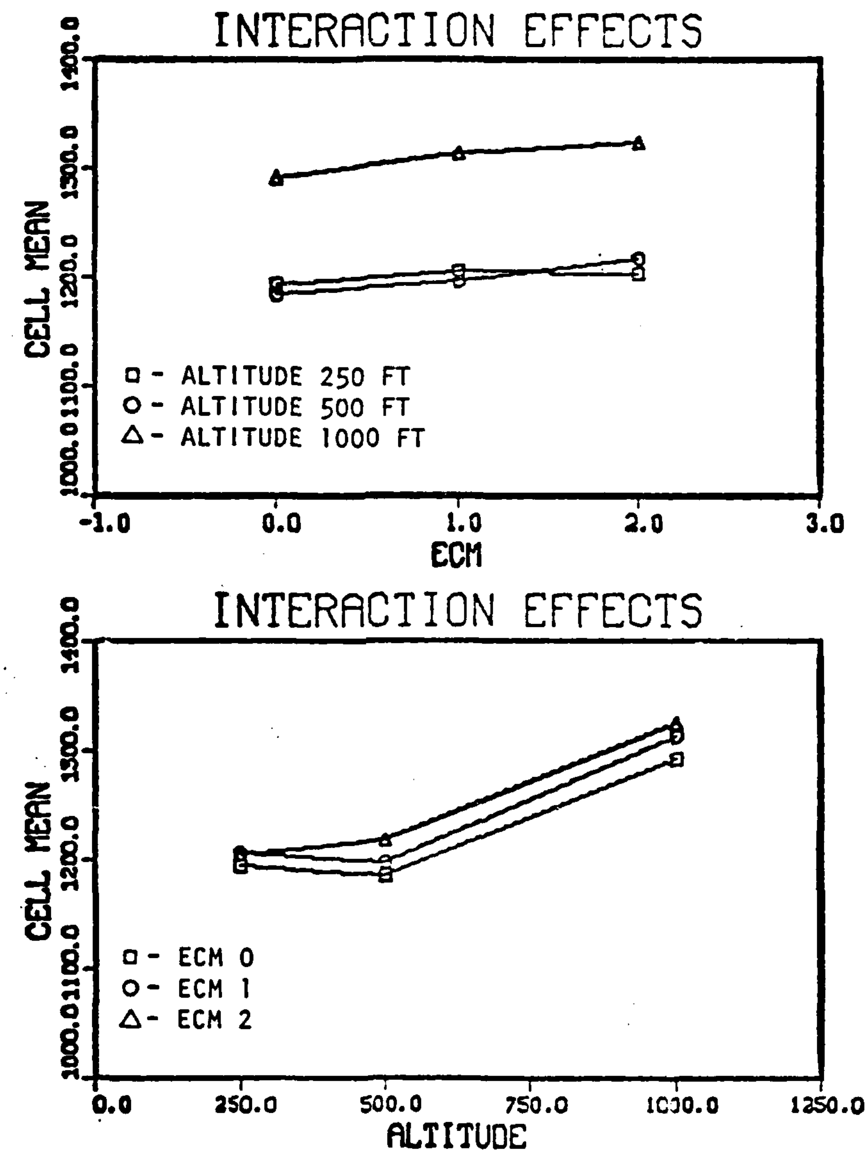

Fig. 24. Interaction Effects Graph

effect of altitude change overshadowed the relatively minor changes in ECM service requirements. The results of the defensive reaction task investigation (Appendix D) indicated that the number of ECM task requirements roughly doubled between 250 and 500 feet but the increase was largely in low service tasks. The change from 500 to 1000 feet increased defensive reaction requirements by only 50 percent but the bulk of the tasks shifted to higher service time tasks. Defensive maneuver tasks increased from .5 percent of all defensive maneuvers to 13 percent when the altitude was raised from 500 to 1000 feet.

In summary, the two-way ANOVA indicated that the only significant effect at a 95 percent confidence level was the effect due to altitude change. This effect was a result of the increase in defensive reaction requirements and the shift to tasks that required longer service times. The increased number of defensive maneuver requirements at 1000 feet had a significant impact on the workload.

One-Way ANOVA

The one-way ANOVA procedure and the Duncan Range test were used to compare the nine configurations modeled. The configurations that were not statistically different were grouped and the groups were ranked with the lowest measure of merit ranked first. The ANOVA portion of the procedure was used to test the hypothesis that all nine configurations (treatments) were the same. The ANOVA indicated that there was a significant difference between some of the configurations. The one-way analysis of variance table in Appendix I does not indicate which of the treatments differ but it does indicate rejection of the hypothesis that all nine are equal.

In order to determine which configurations differed significantly, a multiple range test was used to group the configurations based on a 95 percent confidence level. The Duncan Range test contained in the SPSS package was used to group and rank the configurations. The results were that all configurations at 250 and 500 feet were statistically the same and formed the first group. The second group included all configurations at 1000 feet. The means of the measures of merit for the first group ranged from 1185.4 seconds to 1218.3 seconds, a change of only 2.7 percent. The second group ranged from 1292.5 to 1324.5 seconds, a change of 2.4 percent. The difference between the group means was 109.6 seconds, a change of 8.7 percent. The total change between the lowest mean of 1185.4 seconds and the highest of 1324.5 seconds was 139.1 seconds. Based on the grand mean of all the configurations, this was a change of 11.2 percent.

In summary, the one-way ANOVA indicated that changing the altitude profile from 500 to 250 feet did not cause a statistically significant change in workload regardless of the ECM service requirements. A change from 1000 feet to 250 or 500 feet did cause a statistically significant change in workload. The results of this procedure agreed with the results of the two-way procedure by indicating that ECM service requirements did not significantly change workload.

ANOVA Validity

The assumptions associated with the ANOVA procedure (Ref 14:86) were tested and all assumptions were satisfied. The independence assumption was tested using a Runs Test to support the concept that the data points were independent based on the use of pseudo random number generators in the SLAM procedures. The constant variance assumption was confirmed using the Bartlett Box Test. The normality assumption was tested by computing the residuals and confirming that at least 95 percent were inside two sample standard deviations. The tested hypothesis and results for each test are contained in Appendix J. These tests establish the validity of the use of an ANOVA procedure for data comparison.

Results

The two phases of the data analysis indicated that pilot workload was not the same for the nine workload situations modeled. The results are listed below.

1. ECM service level changes had no statistically significant impact on pilot workload at any of the three altitudes modeled.

2. Pilot workload significantly decreased (8.7 percent) when the aircraft altitude was lowered from 1000 to 500 feet AGL. This resulted from the decreased exposure to enemy threat systems. The number of threats decreased by 32 percent but the requirement to perform defensive maneuvers decreased from 13 percent of all required ECM tasks to .5 percent. This large decrease in the number of long service time tasks caused the significant difference between 1000 and 500 feet AGL.

3. There was no significant difference in workload at 500 and 250 feet AGL.

These results indicate that workload can be analyzed by using a man-machine model. The conclusions that can be drawn from this study are presented in Chapter VII.

VII. Conclusions and Recommendations

This research addressed the problem that a realistic, objective, and relatively inexpensive method for evaluating the impact of a proposed night attack system on pilot workload was not available. The specific area studied was the comparison of pilot workload at 1000, 500 and 250 feet AGL with three possible levels of required ECM service. After the mission and system to be modeled were defined, a network model was constructed using the SLAM simulation language. Parameters for flight control inputs to the model were developed using the A-10 LANTIRN simulator located at the Crew Station Design Facility at Wright-Patterson AFB, Ohio. After parameter refinement and model improvement were completed, data collection was undertaken for the nine cells in the full factorial experiment. The measure of merit used penalized a cell when the pilot did not complete all of the required tasks. Data analysis revealed that ECM service levels were not a significant factor in the comparison of the nine workload levels. Altitude was a significant factor in workload changes. The workload at 250 and 500 feet AGL was significantly lower than the workload at 1000 feet AGL because the intensity of the threat of enemy defense systems was significantly reduced at the lower altitudes. The requirement to perform defensive maneuvers at 500 feet AGL was 3 percent of the requirement at 1000 feet AGL. The workload at 250 and 500 feet was statistically the same.

Conclusions

The conclusions reached as a result of this study are listed below.

1. A comparative pilot workload analysis can be performed using man-machine simulation.

2. If the primary cue for terrain following and terrain avoidance is the terrain following director cue on the HUD, the resulting flight control input distributions do not significantly differ at altitudes of 250, 500 and 1000 feet AGL.

3. A threat management system to relieve a pilot of ECM tasks will not significantly reduce workload even if the system completely eliminates these tasks.

4. The most significant defensive reaction task is the requirement to perform defensive maneuvers to defeat enemy threat systems. This requirement is significantly reduced when the aircraft altitude is changed from 1000 to 500 feet AGL. The main tactic that can be used by a pilot to reduce the threat and thus reduce workload is to fly at his lowest comfort altitude below 1000 feet AGL.

Limitations

The major limitations of this study were the use of a simulator to draw data from which flight control movement distributions could be developed and the simulated threat array that was used to develop the threat input parameters. The magnitude of the limitation of the flight control data could be evaluated in two ways. First, the distributions developed for this thesis could be compared to distributions of required flight control movements developed from equations of dynamic stability for a representative aircraft on a similar profile. The data developed from equations would represent the minimum number of movements required to fly the aircraft over the specified terrain. A comparison of the data from the two sources could be made to determine the similarity of the two groups of distributions. Second, data from an actual aircraft could be gathered on a low-level mission over similar terrain with the intent of comparing the data from the two environments.

The limitations of the threat array are the assumptions made by Leek and Schmitt for their model. The data they used was from unclassified sources. The accuracy of the sources was uncertain but the data was assumed to be representative of the real world. To delete this limitation actual data would have to be used which would require classification of this thesis.

<u>Recommended Areas for Further Study</u>

This model was developed as an example of the utility of man-machine simulation in pilot workload analysis. With this in mind, the next logical extension of this model would be to include the weapon employment phase in the mission profile. This would allow evaluation of workload on varying employment concepts and offer an opportunity to identify workload limitations on multiple target profiles.

The scope of the model could also be expanded to examine the effect of workload on the probability of mission success. This would require more attention to the time allowed between task input and task completion and establishing realistic parameters for the effects of incomplete or incorrect task accomplishment on the mission probability of success.

The final recommended area for further study is the use of the continuous feature of the SLAM language. Using the aircraft equations of state would identify the minimum number of flight control inputs required to maintain aircraft control and indicate a lower boundary on the flight control movements for different mission profiles.

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Appendix A

Model Network Diagram/Flow Charts

This appendix contains the model network diagrams and the flow charts for the subroutines. Figure A-1 is an overview diagram of the network. It shows the large divisions of the model that are shown in detail in later figures.

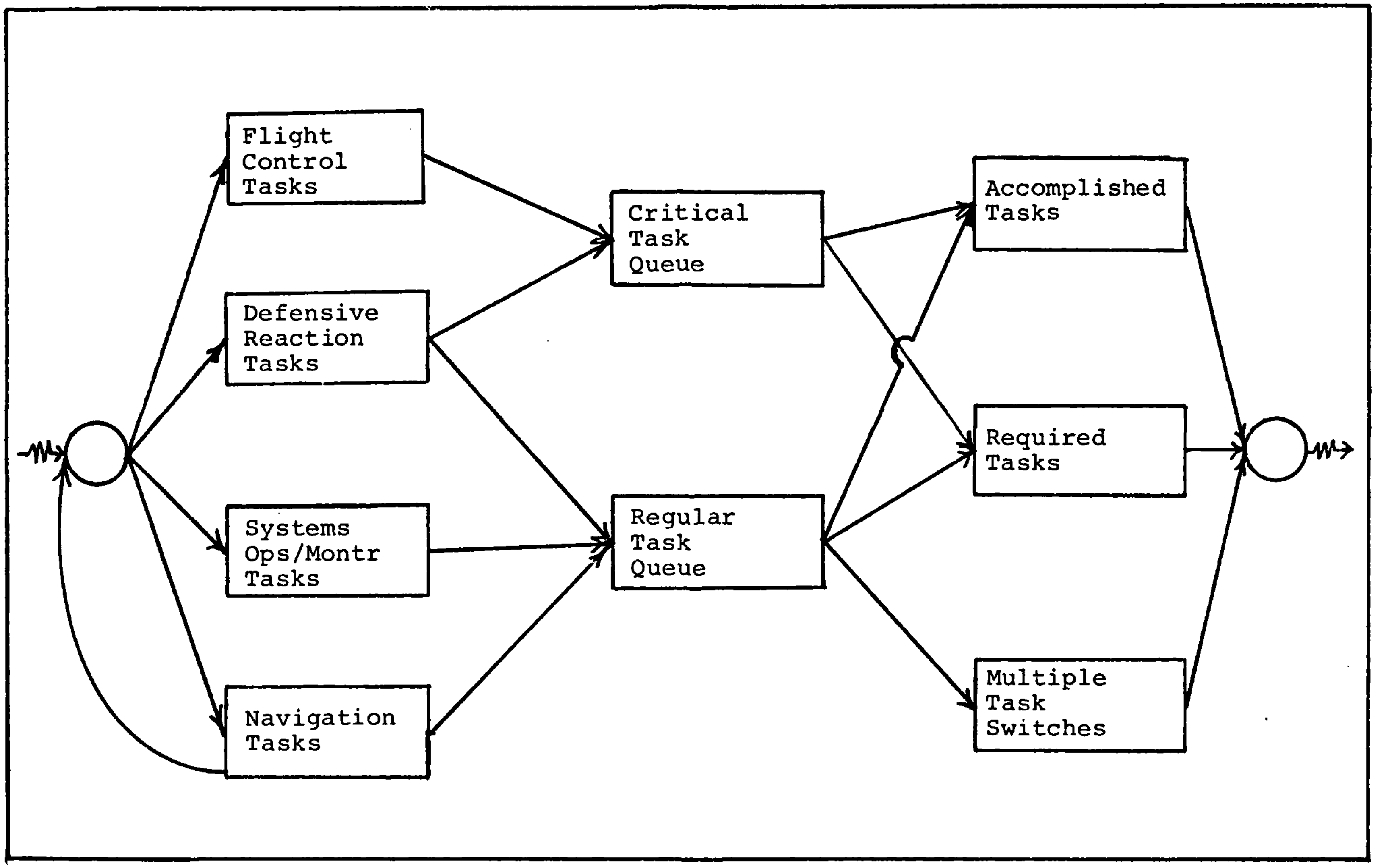


Fig. A-1. Overall Network Schematic

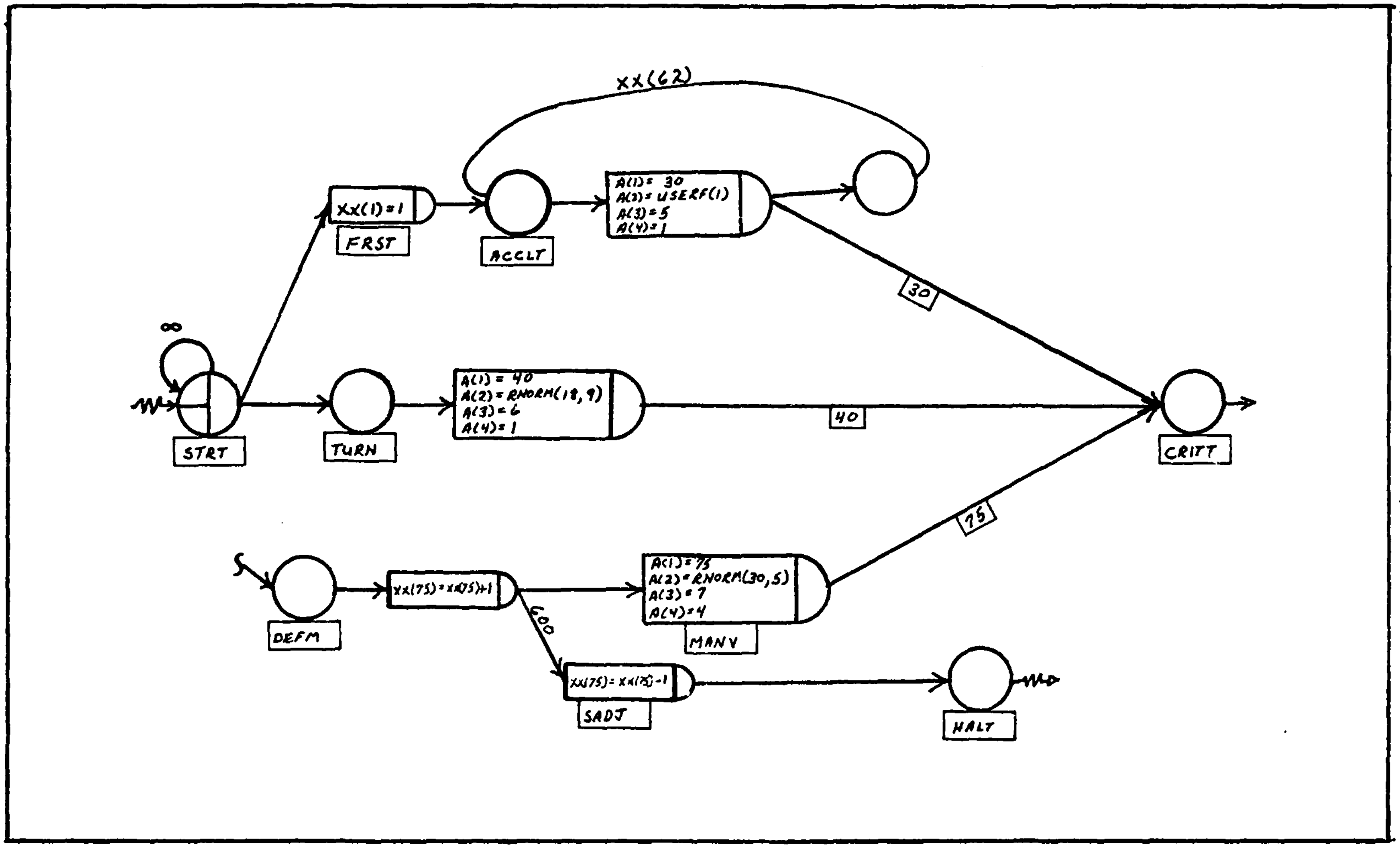


Figure A-2. Flight Control Task Initiation

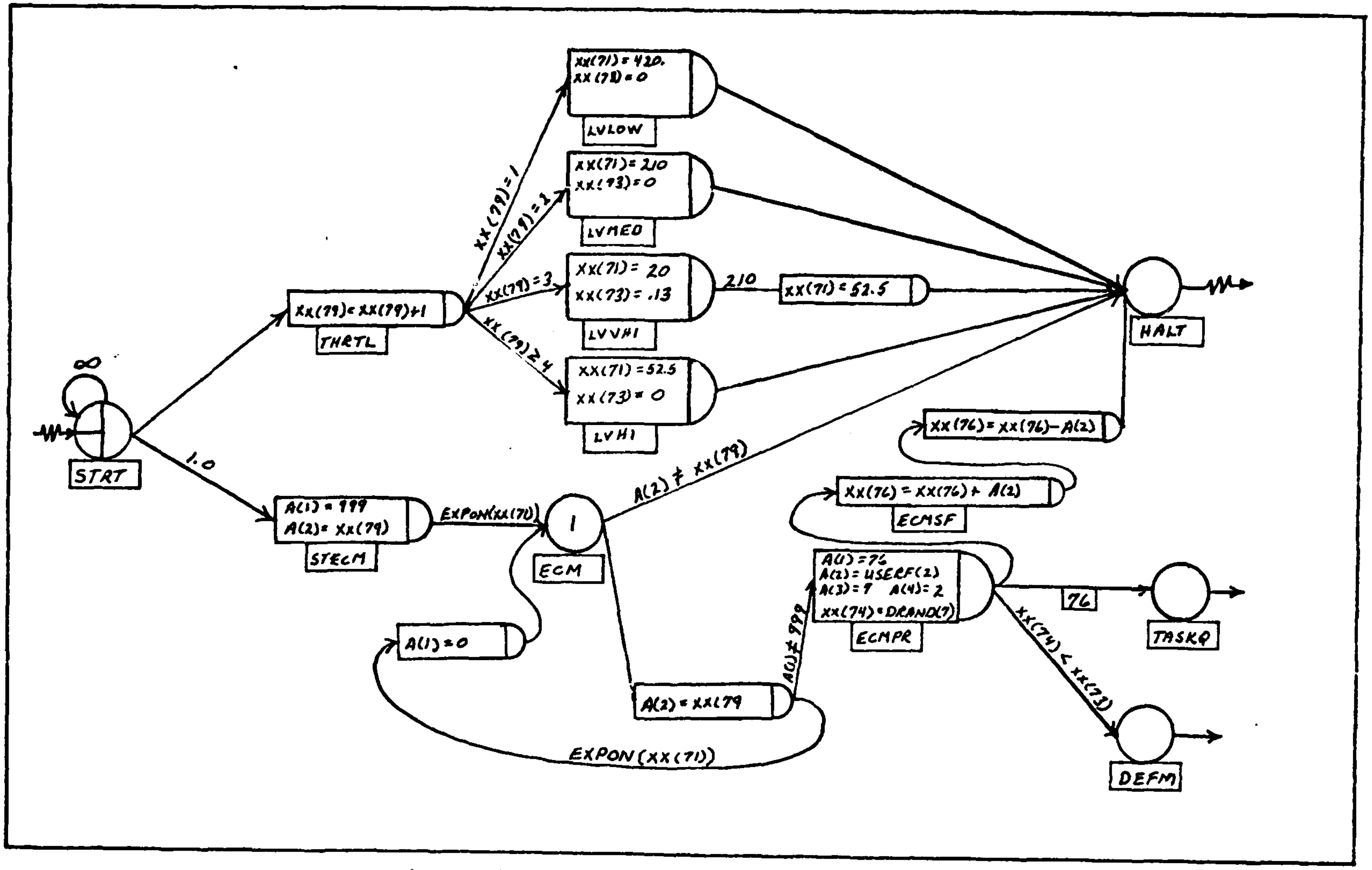


Fig. A-3. Defensive Reaction Task Initiation

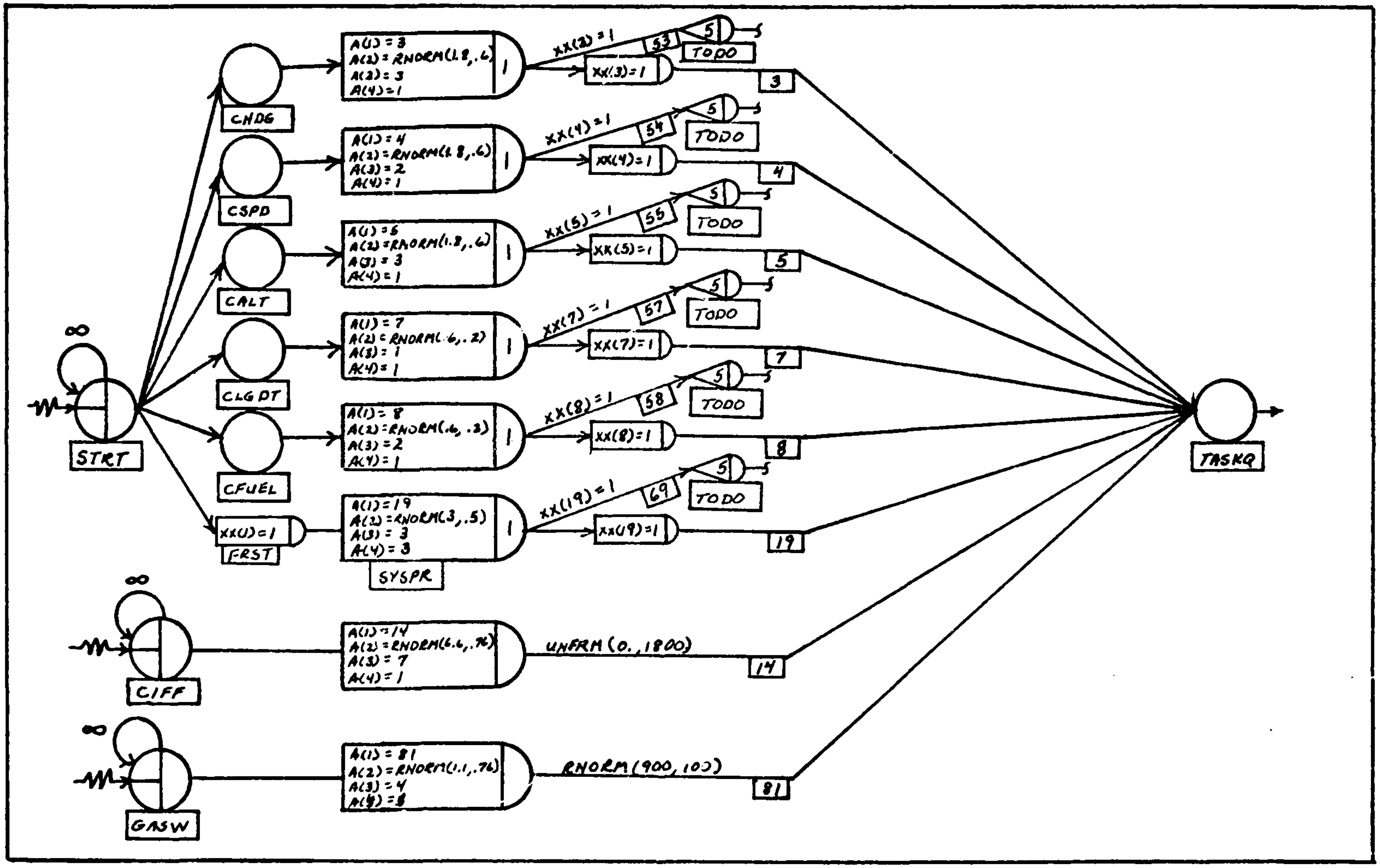


Fig. A-4. Systems Operation/Monitoring Task Initiation

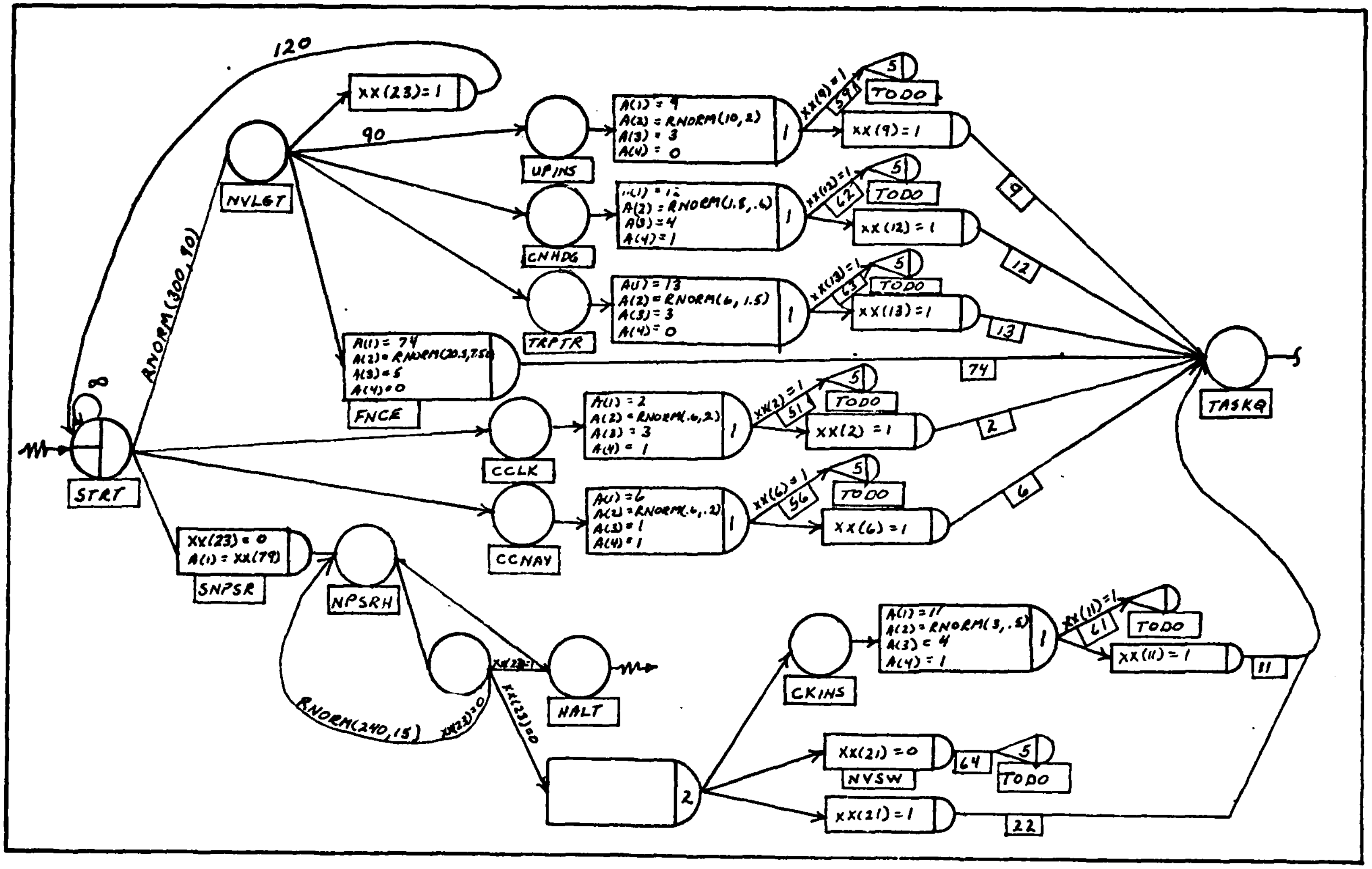


Fig. A-5. Navigation Task Initiation

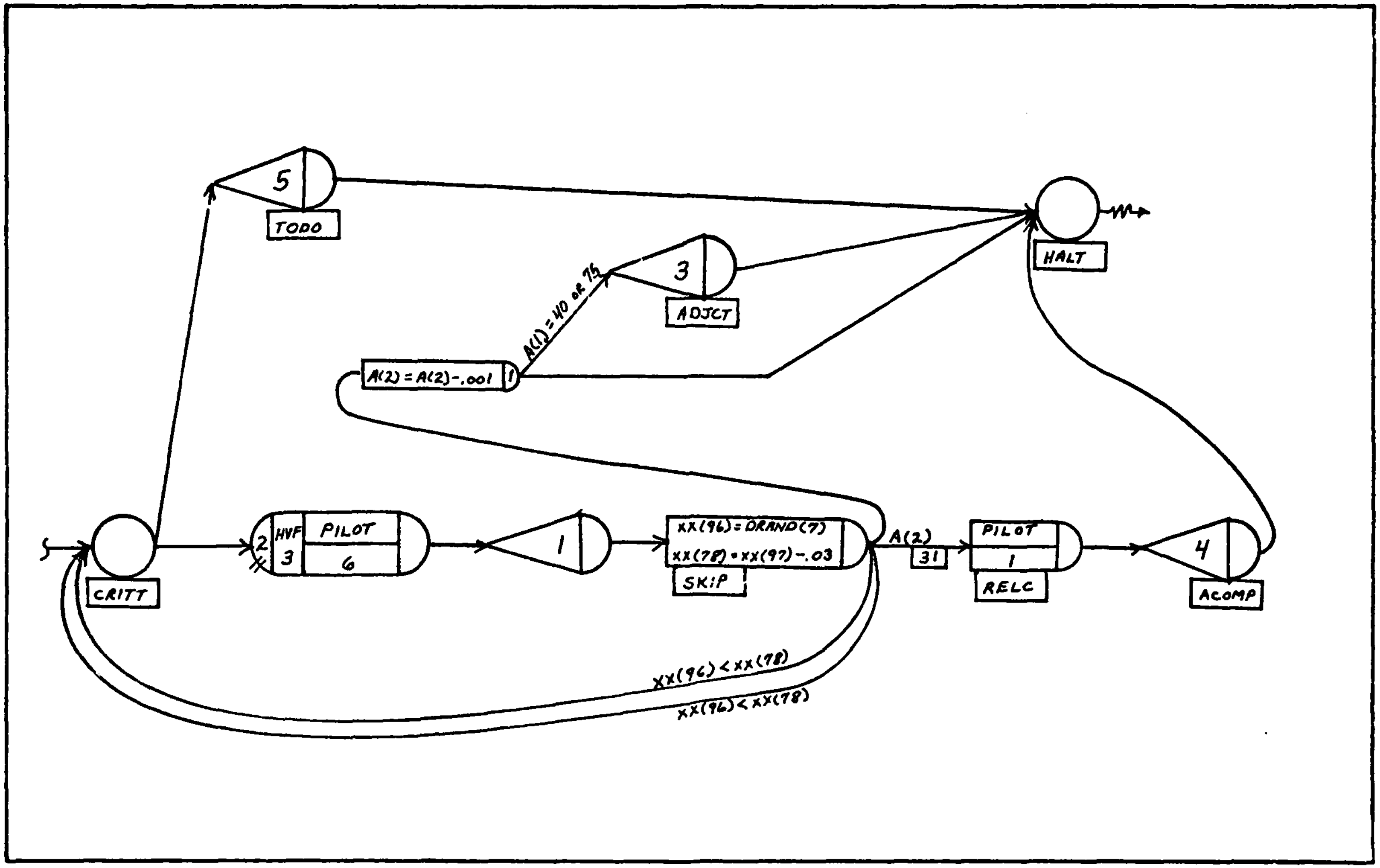


Fig. A-6. Critical Task Queue and Service

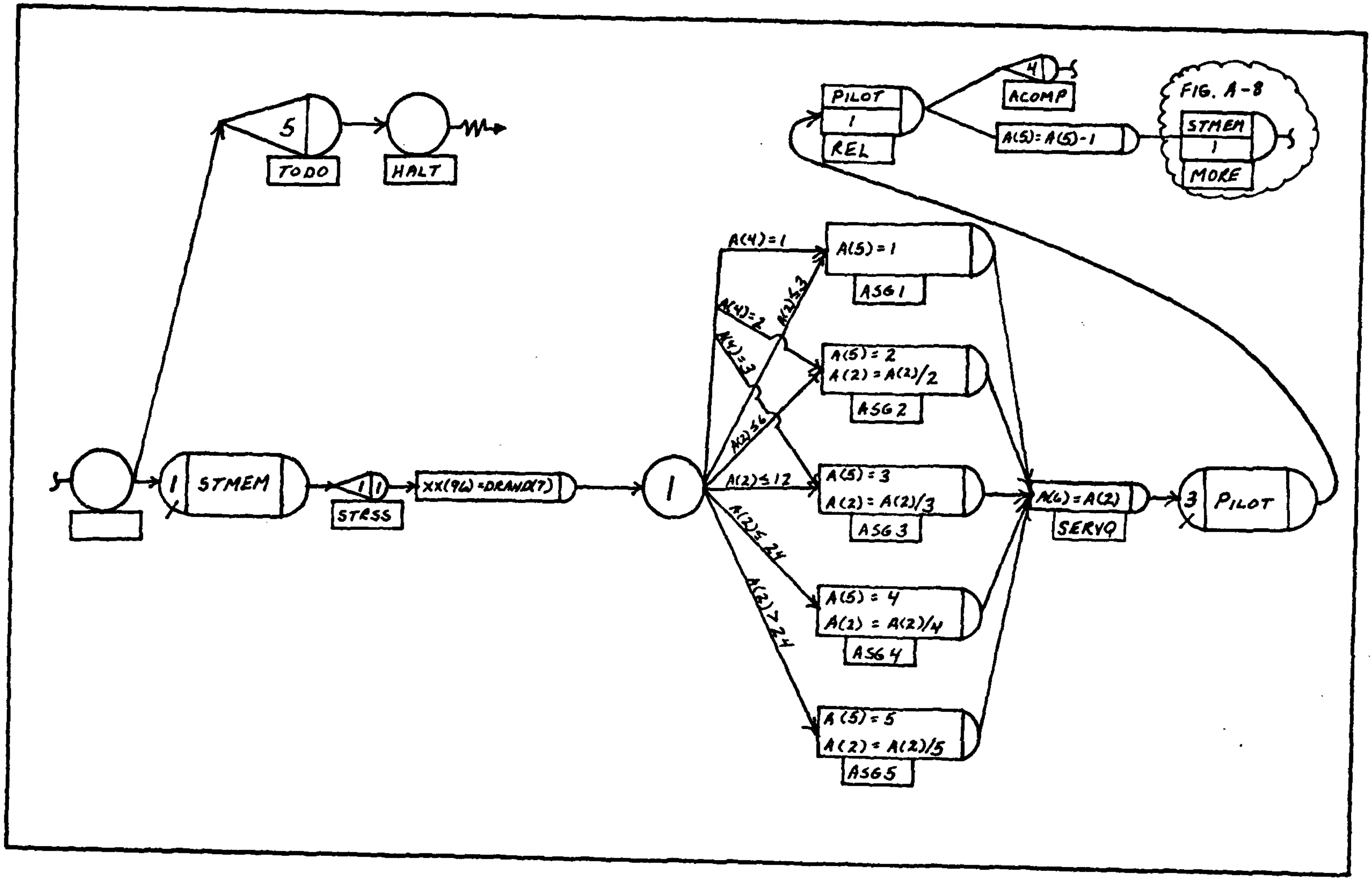


Fig. A-7. Regular Task Queue and Service

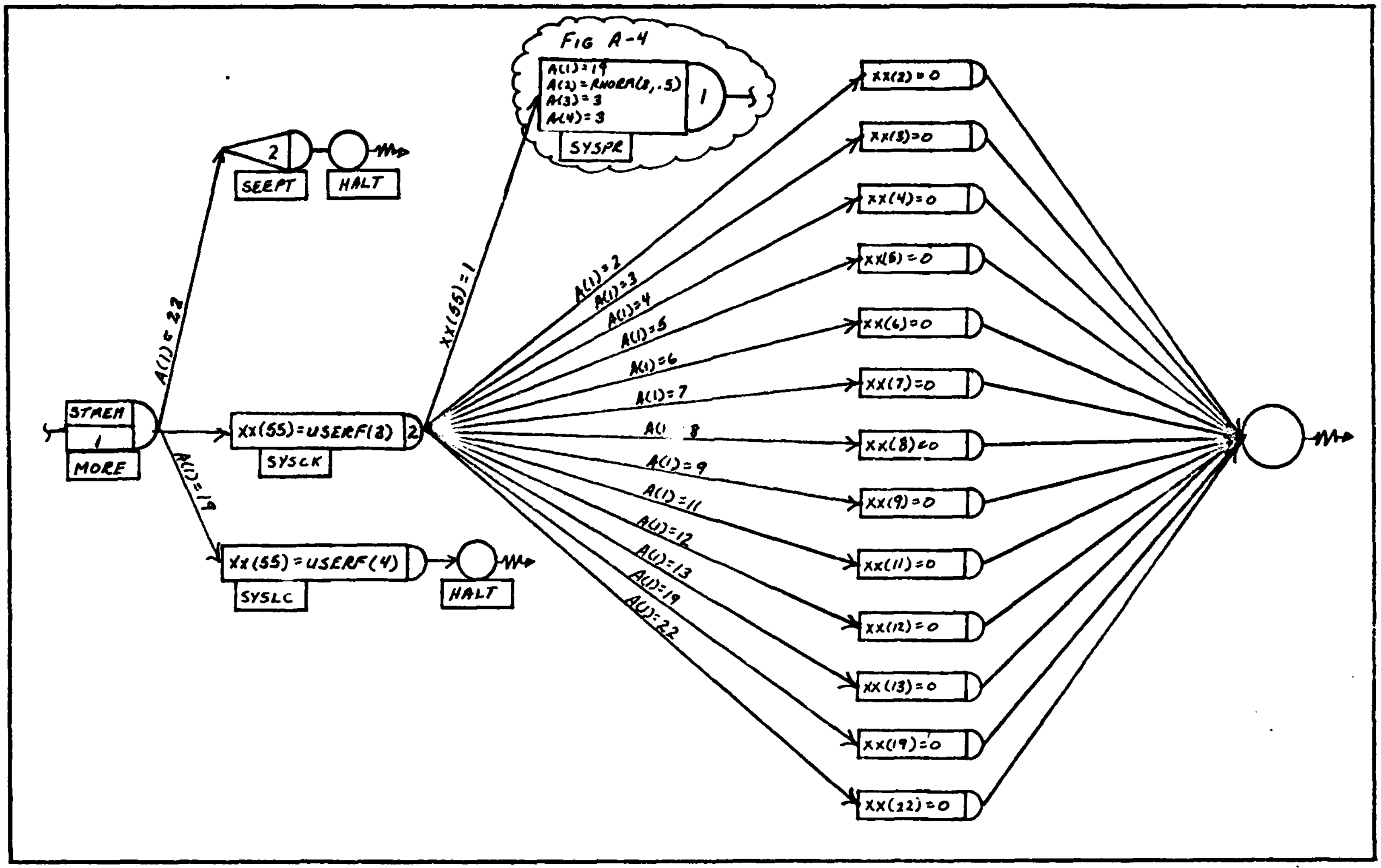


Fig. A-8. Multiple Task Switches

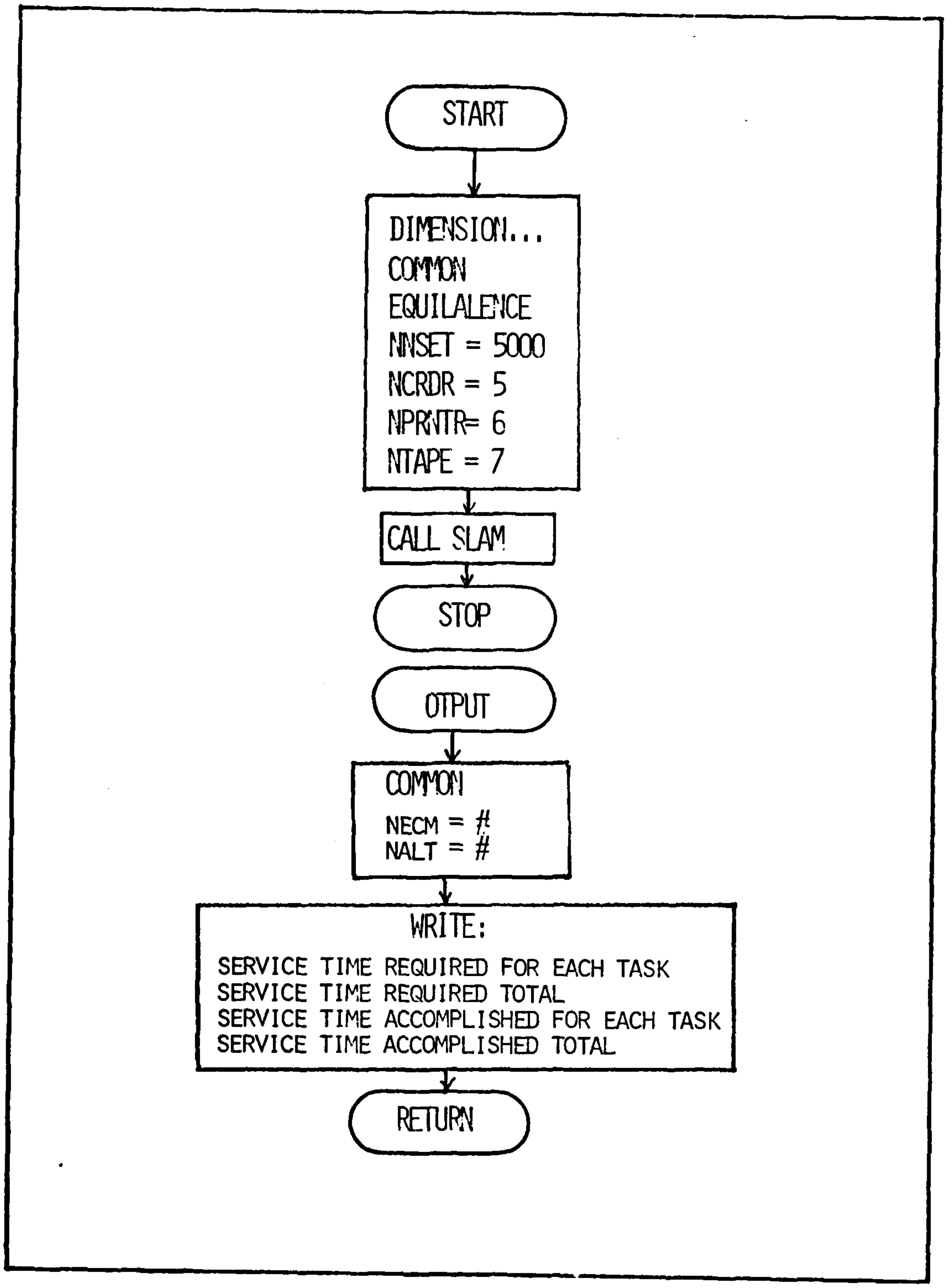


Fig. A-9. Programs MAIN and OTPUT

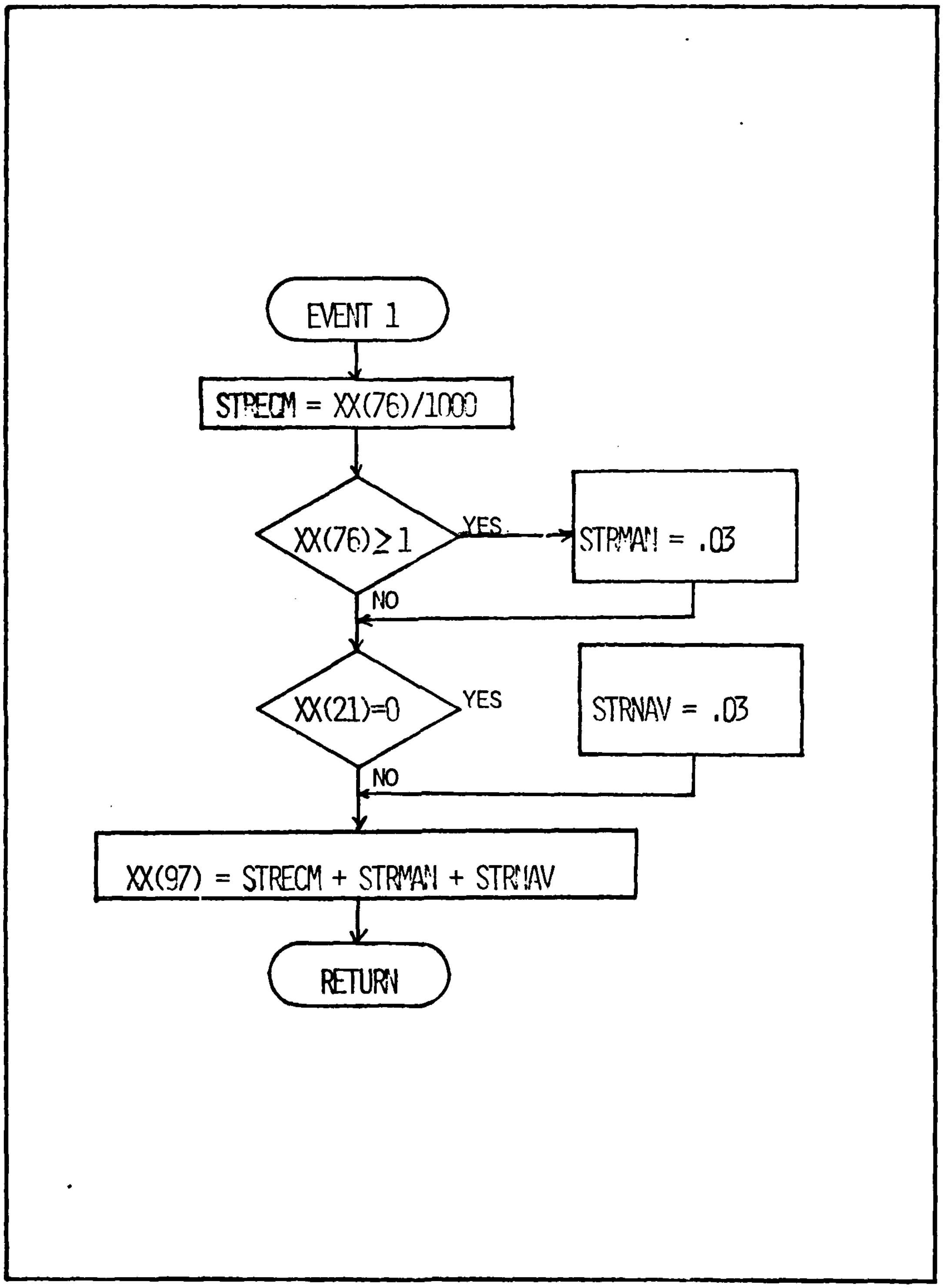


Fig. A-10. EVENT 1

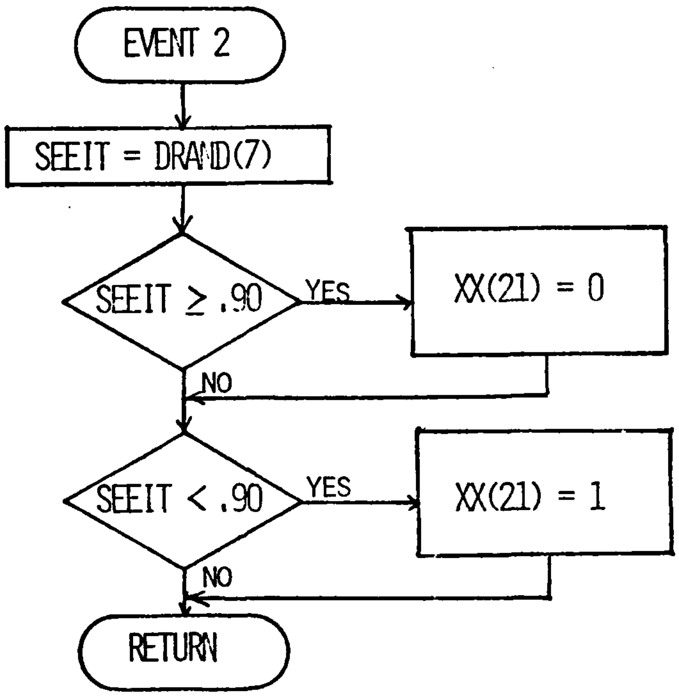


Fig. A-11. EVENT 2

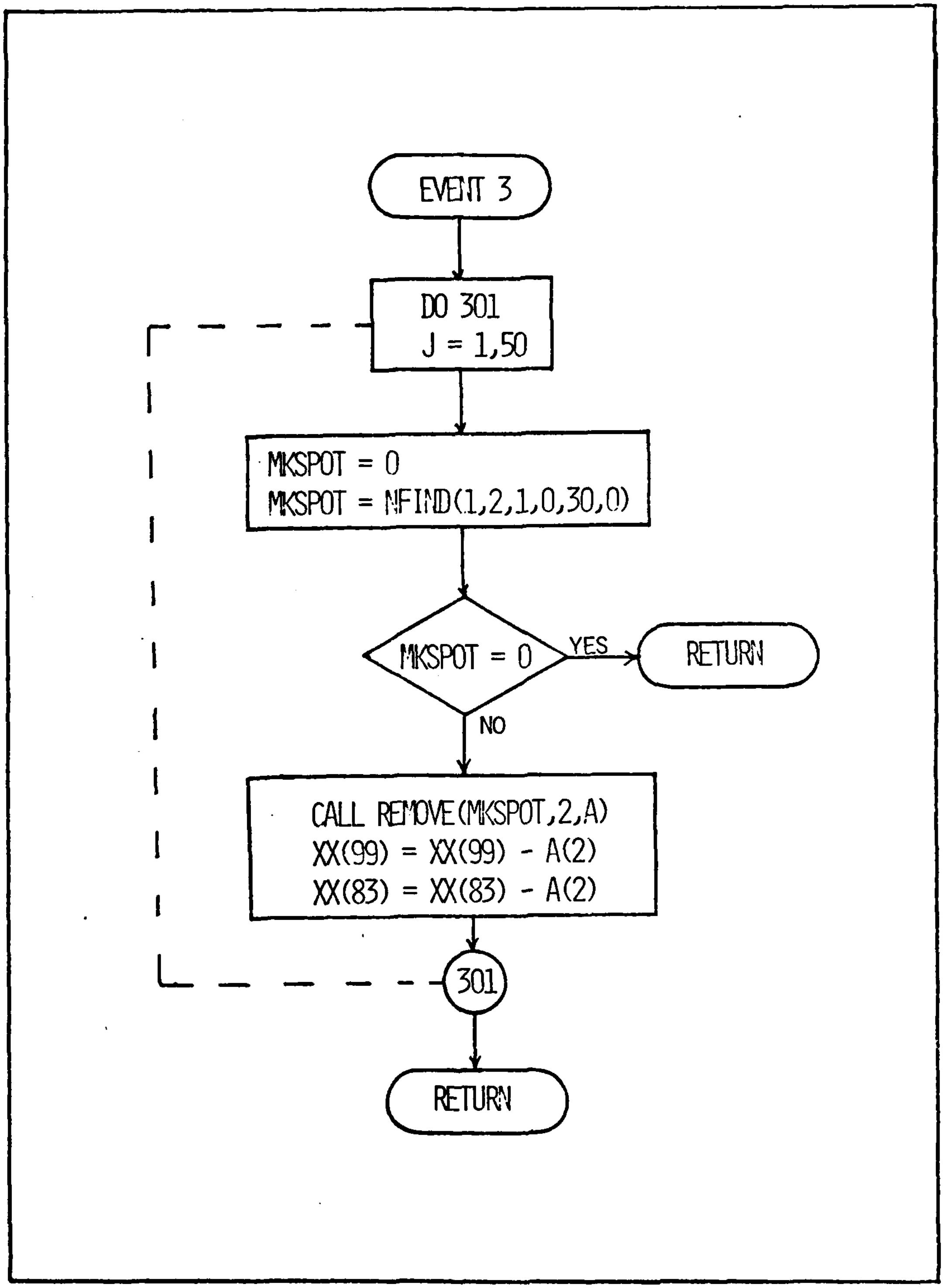


Fig. A-12. EVENT 3

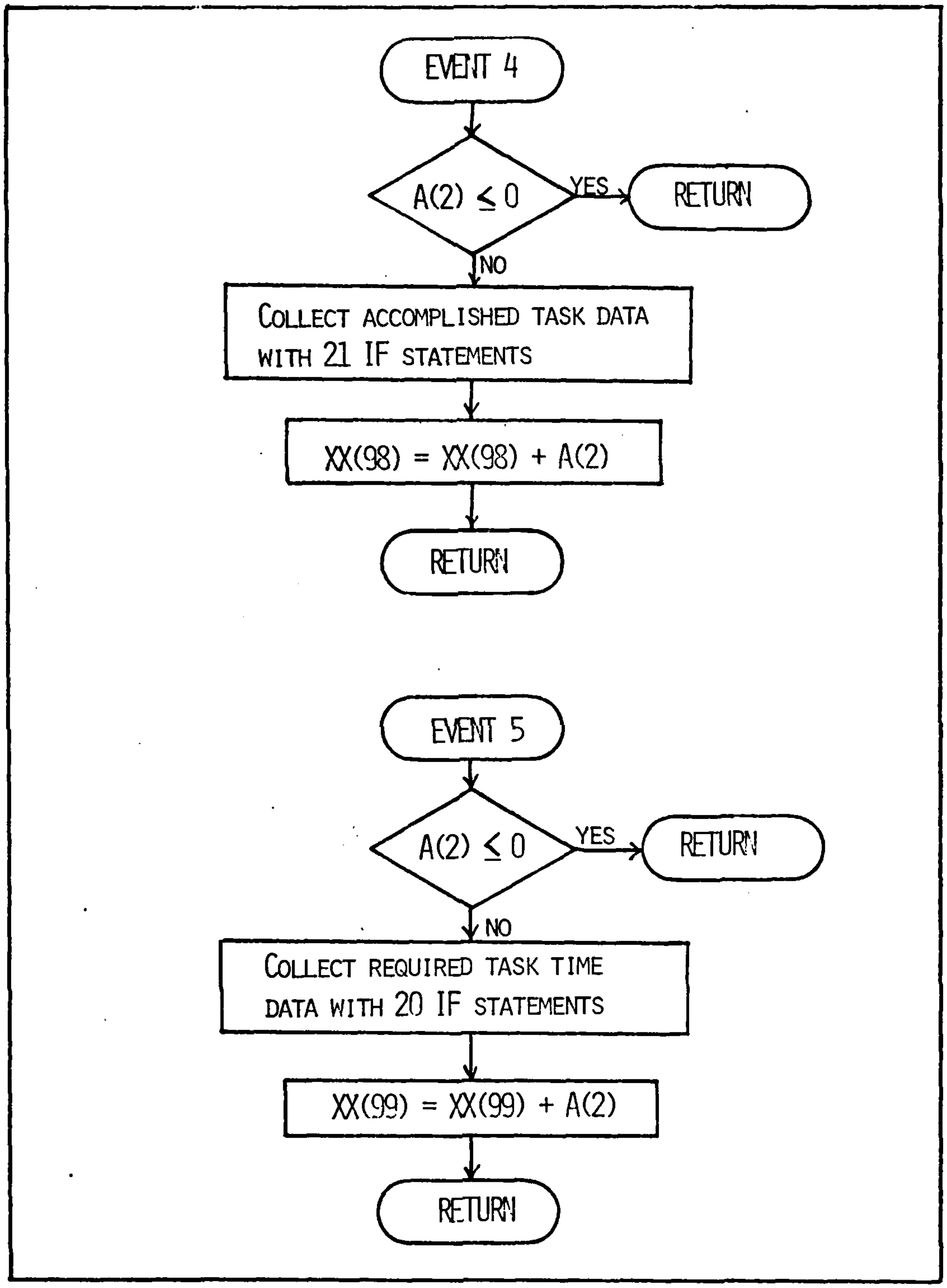


Fig. A-13. EVENTS 4 and 5

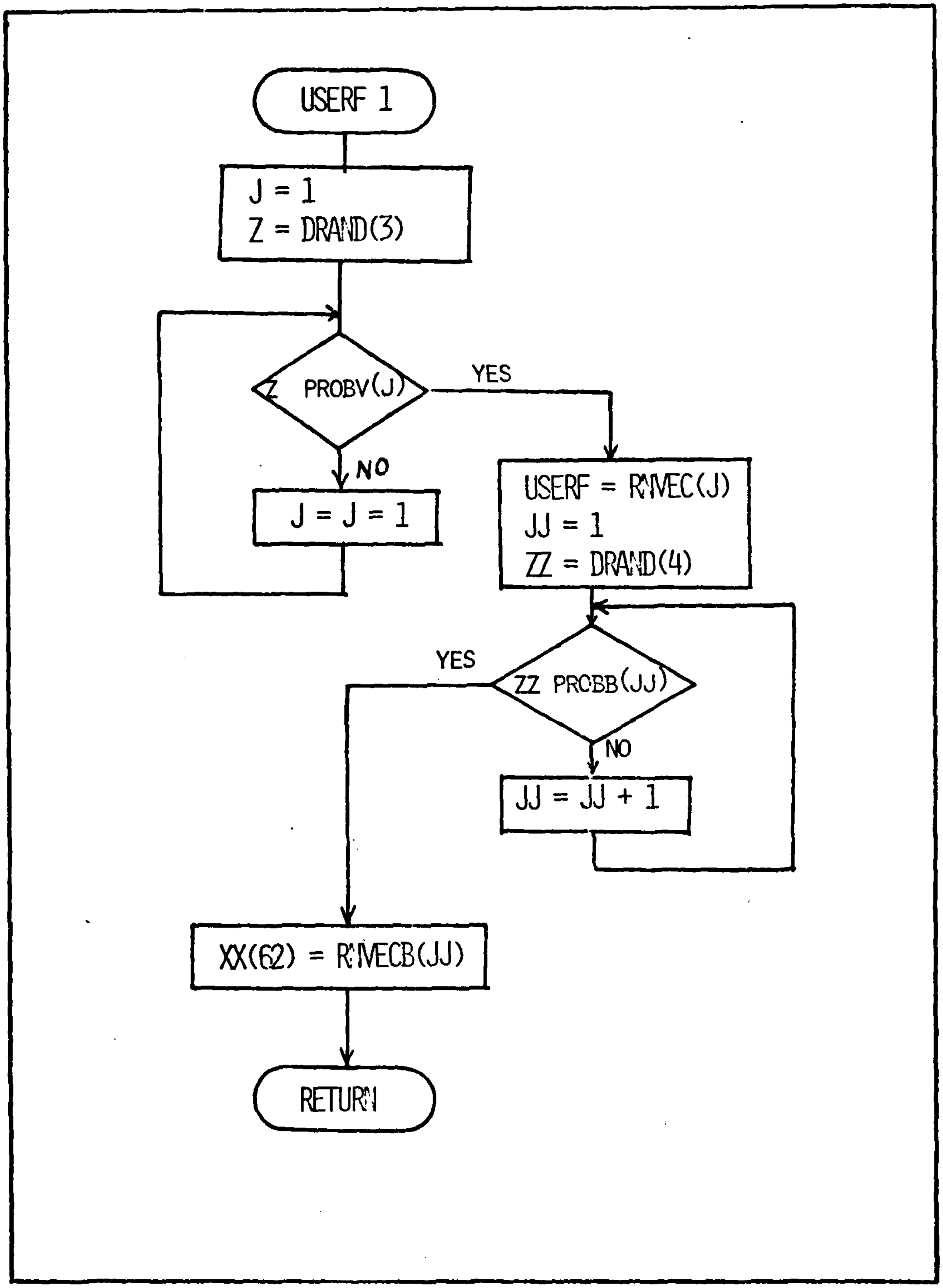


Fig. A-14. USERF 1

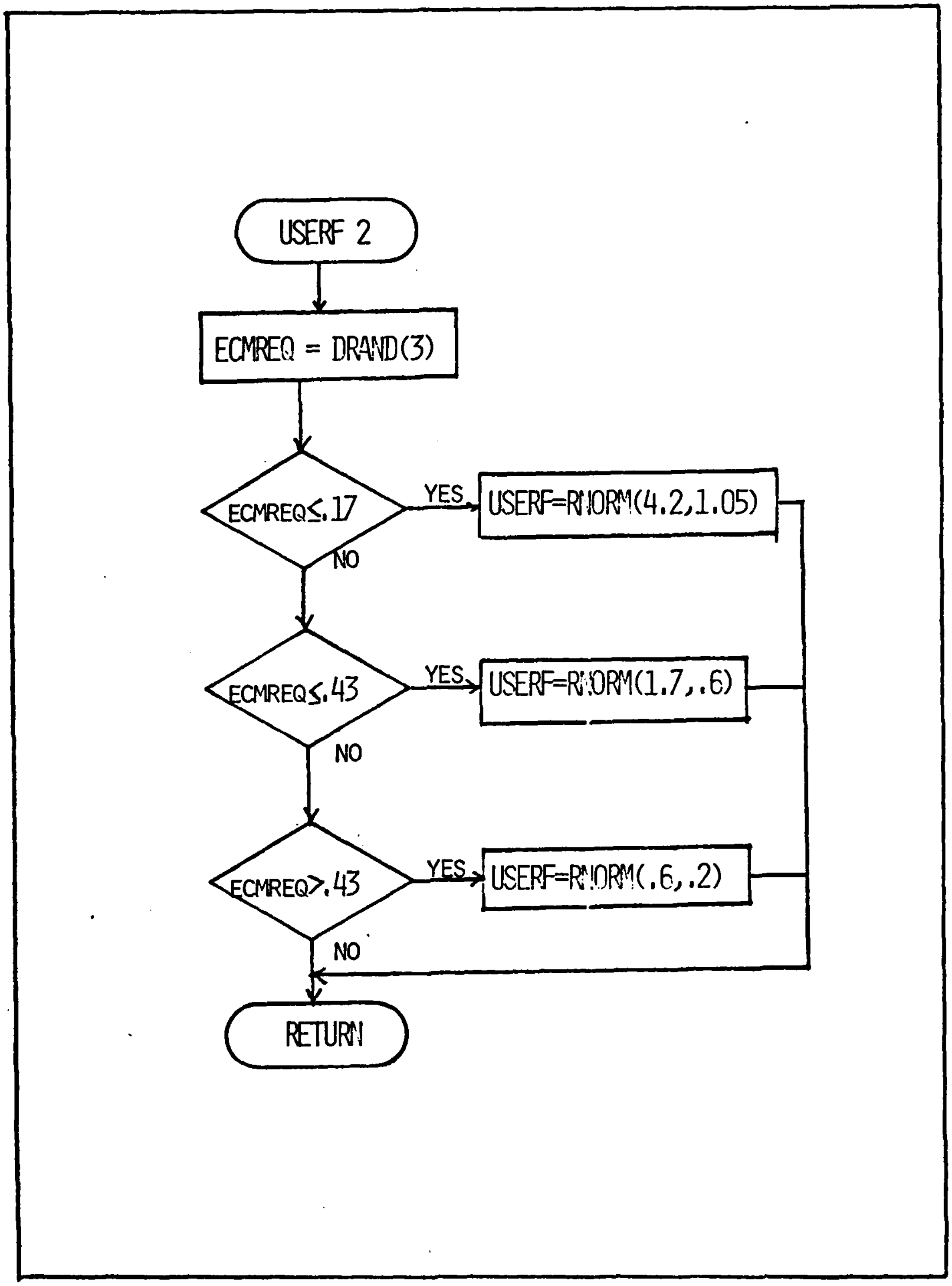


Fig. A-15. USERF 2

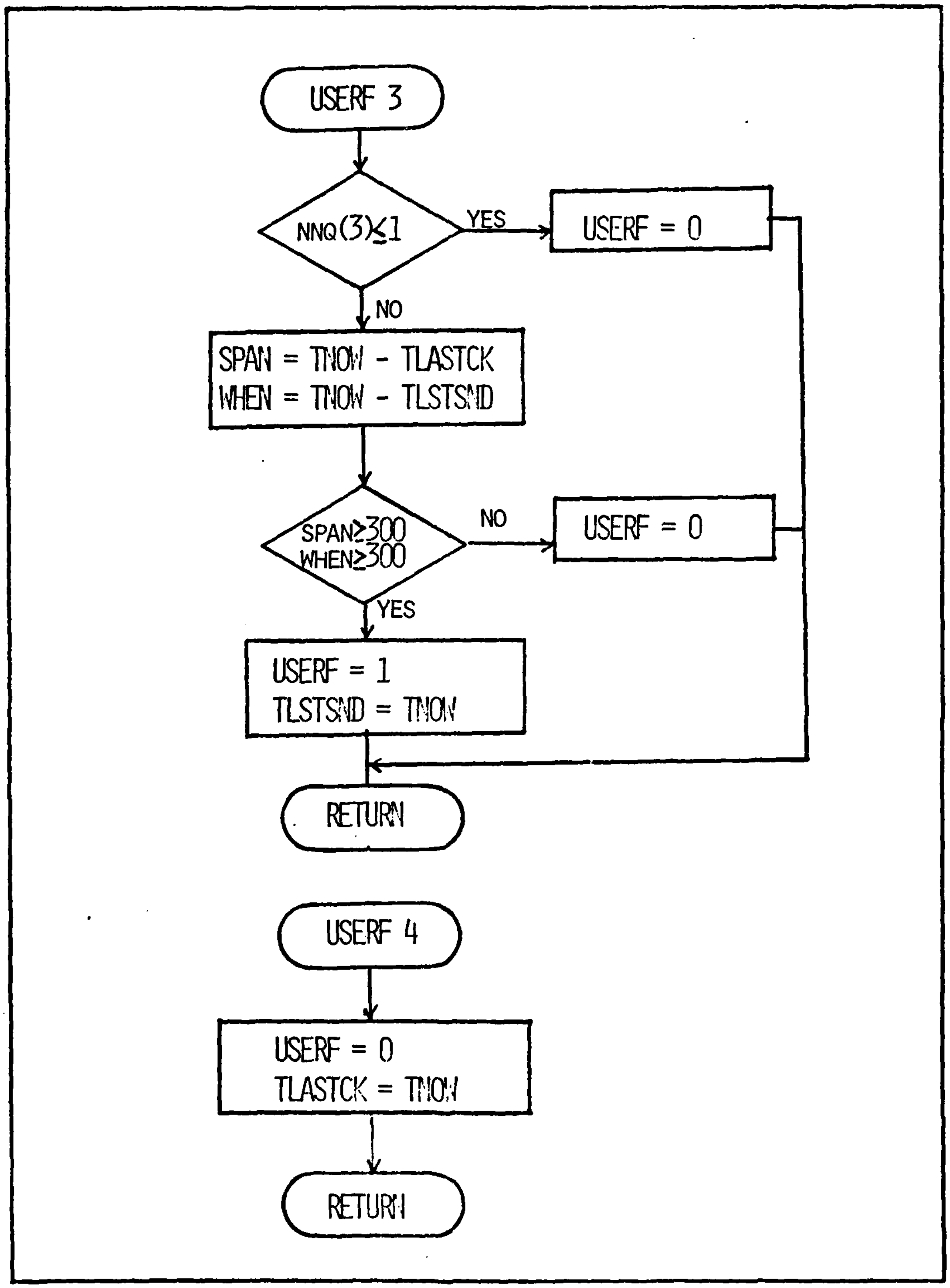


Fig. A-16. USERF 3 and 4

Appendix B

Model Code Listing

This appendix contains the model computer code listing. Description and documentation is contained in the listing.

```
 A1I,CM133000,T160,I0100. T790541,GROVES,4421.
ATTACH,SLAM,ID=AFIT.
FTN,SYSEDIT.
ATTACH,TAPE8,REQUIRE,CY=1.
ATTACH,TAPE9,DATA,CY=1.
SKIPF,TAPE8,1,17,B.
SKIPF,TAPE9,1,17,B.
COPYL,SLAM,LGO,RUN,,RA.
RUN,PL=20000.
EXTEND,TAPE8.
EXTEND,TAPE9.
REWIND,TAPE8.
REWIND,TAPE9.
RETURN,TAPE8.
RETURN,TAPE9.

C
      PROGRAM MAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT
     *,TAPE7,TAPE8,TAPE9)
      DIMENSION NSET(5000)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,
     *NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
     *TNEXT,TNOW,XX(100)
      COMMON QSET(5000)
      EQUIVALENCE (NSET(1),QSET(1))
      NNSET=5000
      NCRDR=5
      NPRNT=6
      NTAPE=7
      CALL SLAM
      STOP
      END
C
C *************************************************************
C **    GLOSSARY OF GLOBAL VARIABLES                        **
C * XX(1)-SWITCH TO IDENTIFY THE FIRST NAV LEG               *
C * XX(2) THRU XX(13)-SWITCHES TO IDENTIFY AN UNCOMPLETED    *
C *         TASK IN THE QUEUE, THE (#) CORRESPONDS TO THE    *
C *         FIRST ATTRIBUTE VALUE OF THE TASK                *
C * XX(19)-SWITCH TO IDENTIFY AN UNCOMPLETED TASK 19        *
C * XX(21)-SWITCH TO INDICATE THE SUCCESS/FAILURE OF A       *
C *         NAV POINT SEARCH                                 *
C * XX(22)-SWITCH TO IDENTIFY AN INCOMPLETE NAV TASK IN      *
C *         THE QUEUE                                        *
C * XX(23)-SWITCH TO ALLOW/STOP NAV POINT SEARCHES           *
C * XX(32) THRU XX(39)- SAME AS XX(20) THRU XX(90) EXCEPT    *
C *         THESE WERE FOR TASKS COMPLETED                   *
C *      XX(#)       TASK #        COMPLETED/REQUIRED
C *   20,30,40,50  2,3,4,5          REQUIRED                 *
C *   60,70,80,90   6,7,8,9          REQUIRED                *
C *   32 THRU 39   2 THRU 9         COMPLETED                *
C *   41 THRU 44   11 THRU 14       COMPLETED                *
C *   45 THRU 48   19,22,30,40      COMPLETED                *
```

```
C  *  14,15,16,18  74,75 76,81      COMPLETED            *
C  *  91 THRU 94   11 THRU 14       REQUIRED             *
C  *     95           19            REQUIRED             *
C  *  82,83,84,85  22,30,40,74,75   REQUIRED             *
C  *  86,87,89     75,76,81         REQUIRED             *
C  *     98         TOTAL           COMPLETED            *
C  *     99         TOTAL           REQUIRED             *
C  * XX(55)-SWITCH TO ALLOW AN OPS CHECK TASK            *
C  * XX(71)-PARAMETER FOR DEFENSIVE REACTION INPUT       *
C  * XX(73)-PARAMETER FOR RATIO OF DEF MANEUVERS REQUIRED *
C  *        TO DEF REACTIONS INITIATED                   *
C  * XX(74)-RANDOM NUMBER TO TEST PROPER TASK ACCOMPLISH- *
C  *        MENT, I. E. STRESS TEST                      *
C  * XX(75)-DEFENSIVE MANEUVER STRESS SWITCH             *
C  * XX(76)-ECM STRESS FACTOR PARAMETER                  *
C  * XX(78)-DUMMY PARAMETER TO REMOVE NORMAL ERROR RATE  *
C  *        WHEN TESTING FLIGHT CONTROL TASKS FOR PROPER *
C  *        COMLETEION                                   *
C  * XX(79)-NAV LEG COUNTER                              *
C  * XX(96)-RANDOM NUMBER FOR STRESS TEST OF FLIGHT CONTROL*
C  * TASKS                                               *
C  * XX(97)-TOTAL STRESS VARIABLE                        *
C  * XX)98)-COMPLETED SERVICE TIME                       *
C  * XX(99)-REQUIRED SERVICE TIME                        *
C  *******************************************************
C  *******************************************************
C
C >> EVENT SUBROUTINES FOR STRESS , NAVIGATION SUCCESS , <<
C >> ELIMINATION OF EXTRA FLIGHT CONTROL INPUTS &        <<
C >> COLLECTING DATA ON TASK TIMES                       <<
C
      SUBROUTINE EVENT (I)
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,
     *NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
     *TNEXT,TNOW,XX(100)
      DIMENSION A(7)
C
C >> INITILIZE STRESS FACTOR TERMS <<
      DATA STRECM,STRNAV,STRMAN,TOTSTR /4*0./
      GO TO (1,2,3,4,5),I
C
C >> COMPUTE STRESS IMPACTS ON SERVICE TIMES <<
C
C >> ECM STRESS = CURRENT 2 MIN. MEMORY OF ECM SERVICE
C    TIMES/1000 <<
1     STRECM=XX(76)/1000.
C >> IF THE DEFENSIVE MANEUVER SWITCH IS SET INCREASE
C    THE STRESS FACTOR BY .03 <<
      IF(XX(75).GE.1.) STRMAN= .03
C >> IF THE LAST NAV POINT WAS NOT SEEN INCREASE THE
C    STRESS FACTOR BY .03 <<
      IF(XX(21).EQ.0.) STRNAV= .03
C >> SUM THE STRESS FACTORS <<
```

```
      XX(97)=STRECM + STRMAN + STRNAV
      RETURN
C
C >> DETERMINE IF THE NAV POINT WAS SEEN <<
C
2     SEEIT = DRAND(7)
C >> THERE IS A 10% CHANCE THAT THE NAV POINT WILL
C    NOT BE SEEN--SET THE SWITCH TO 0. IF NOT SEEN <<
      IF(SEEIT.GE..90) XX(21)=0.
      IF(SEEIT.LT..90) XX(21)=1.
      RETURN
C
C >> REMOVE CONTROL INPUTS THAT WERE GENERATED WHILE <<
C >> TASKS 40 OR 75 WERE BEING SERVICED BECAUSE THESE <<
C >> TASKS WOULD BE DONE AS PART OF TASKS 40 & 75  <<
3     DO 301 J=1,50
      MKSPOT=0
      MKSPOT = NFIND(1,2,1,0,30.,0.)
      IF(MKSPOT.EQ.0) GO TO 302
      CALL RMOVE(MKSPOT,2,A)
      XX(99)=XX(99)-A(2)
      XX(83)=XX(83)-A(2)
301   CONTINUE
302   RETURN
C
C >> EVENTS 4 & 5 ARE USED TO COLLECT TASK TIME  <<
C >> DATA FOR ANALYSIS--EVENT 4 COLLECTS DATA ON <<
C >> COMPLETED TASKS WHILE EVENT 5 COLLECTS DATA <<
C >> ON TASKS THAT WERE TO BE ACCOMPLISHED       <<
C >> TOTAL TASKS COMPLETED <<
4     IF(ATRIB(2).LT.0.) RETURN
      IF(ATRIB(1).EQ.2.) XX(32)=XX(32) + ATRIB(2)
      IF(ATRIB(1).EQ.3.) XX(33)=XX(33) + ATRIB(2)
      IF(ATRIB(1).EQ.4.) XX(34)=XX(34) + ATRIB(2)
      IF(ATRIB(1).EQ.5.) XX(35)=XX(35) + ATRIB(2)
      IF(ATRIB(1).EQ.6.) XX(36)=XX(36) + ATRIB(2)
      IF(ATRIB(1).EQ.7.) XX(37)=XX(37) + ATRIB(2)
      IF(ATRIB(1).EQ.8.) XX(38)=XX(38) + ATRIB(2)
      IF(ATRIB(1).EQ.9.) XX(39)=XX(39) + ATRIB(2)
      IF(ATRIB(1).EQ.11.) XX(41)=XX(41) + ATRIB(2)
      IF(ATRIB(1).EQ.12.) XX(42)=XX(42) + ATRIB(2)
      IF(ATRIB(1).EQ.13.) XX(43)=XX(43) + ATRIB(2)
      IF(ATRIB(1).EQ.14.) XX(44)=XX(44) + ATRIB(2)
      IF(ATRIB(1).EQ.19.) XX(45)=XX(45) + ATRIB(2)
      IF(ATRIB(1).EQ.22.) XX(46)=XX(46) + ATRIB(2)
      IF(ATRIB(1).EQ.30.) XX(47)=XX(47) + ATRIB(2)
      IF(ATRIB(1).EQ.40.) XX(48)=XX(48) + ATRIB(2)
      IF(ATRIB(1).EQ.74.) XX(14)=XX(14) + ATRIB(2)
      IF(ATRIB(1).EQ.75.) XX(15)=XX(15) + ATRIB(2)
      IF(ATRIB(1).EQ.76.) XX(16)=XX(16) + ATRIB(2)
      IF(ATRIB(1).EQ.81.) XX(18)=XX(18) + ATRIB(2)
      XX(98) = XX(98) + ATRIB(2)
      RETURN
C
```

```
C >> TOTAL TASKS REQUIRED <<
5     IF(ATRIB(2).LT.0.) RETURN
      IF(ATRIB(1).EQ.2.) XX(20)=XX(20) + ATRIB(2)
      IF(ATRIB(1).EQ.3.) XX(30)=XX(30) + ATRIB(2)
      IF(ATRIB(1).EQ.4.) XX(40)=XX(40) + ATRIB(2)
      IF(ATRIB(1).EQ.5.) XX(50)=XX(50) + ATRIB(2)
      IF(ATRIB(1).EQ.6.) XX(60)=XX(60) + ATRIB(2)
      IF(ATRIB(1).EQ.7.) XX(70)=XX(70) + ATRIB(2)
      IF(ATRIB(1).EQ.8.) XX(80)=XX(80) + ATRIB(2)
      IF(ATRIB(1).EQ.9.) XX(90)=XX(90) + ATRIB(2)
      IF(ATRIB(1).EQ.11.) XX(91)=XX(91) + ATRIB(2)
      IF(ATRIB(1).EQ.12.) XX(92)=XX(92) + ATRIB(2)
      IF(ATRIB(1).EQ.13.) XX(93)=XX(93) + ATRIB(2)
      IF(ATRIB(1).EQ.14.) XX(94)=XX(94) + ATRIB(2)
      IF(ATRIB(1).EQ.19.) XX(95)=XX(95) + ATRIB(2)
      IF(ATRIB(1).EQ.22.) XX(82)=XX(82) + ATRIB(2)
      IF(ATRIB(1).EQ.30.) XX(83)=XX(83) + ATRIB(2)
      IF(ATRIB(1).EQ.40.) XX(84)=XX(84) + ATRIB(2)
      IF(ATRIB(1).EQ.74.) XX(85)=XX(85) + ATRIB(2)
      IF(ATRIB(1).EQ.75.) XX(86)=XX(86) + ATRIB(2)
      IF(ATRIB(1).EQ.76.) XX(87)=XX(87) + ATRIB(2)
      IF(ATRIB(1).EQ.81.) XX(89)=XX(89) + ATRIB(2)
      XX(99) = XX(99) + ATRIB(2)
      RETURN
      END
C
C
      SUBROUTINE OTPUT
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,
     *NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
     *TNEXT,TNOW,XX(100)
C
C >> NECM = ECM LEVEL
C >> NALT = ALTITUDE
C  ..........................................
C............................................
      NECM=2
      NALT=3
C............................................
C  ............................................
C
      WRITE(6,1001) (XX(I),I=20,90,10)
      WRITE(6,1002) (XX(I),I=91,95),(XX(I),I=82,89),XX(99)
C
      WRITE(6,2001) (XX(I),I=32,39)
      WRITE(6,2002) (XX(I),I=41,48)
      WRITE(6,2003) (XX(I),I=14,18),XX(98)
      WRITE(8,3001) (XX(I),I=20,90,10),(XX(I),I=91,95),
     *(XX(I),I=82,89),XX(99)
      WRITE(8,3001)(XX(I),I=32,39),(XX(I),I=41,48)
     *,(XX(I),I=14,18),XX(98)
      WRITE(9,4001) NECM,NALT,XX(78),XX(99)
4001  FORMAT(1X,I2,1X,I2,1X,F10.3,1X,F10.3)
```

```
C
1001  FORMAT(1X,"TASK TIMES TO ACCOMPLISH"//"  T2 = ",F8.3,
     *" T3 = ",F8.3," T4 = ",F8.3," T5 = ",F8.3," T6 = ",F8.3
     *," T7 = ",F8.3," T8 = ",F8.3," T9 = ",F8.3)
1002  FORMAT(1X," T11 = ",F8.3," T12 = ",F8.3," T13 = ",F8.3,
     *" T14 = ",F8.3" T19 = ",F8.3," T22 = ",F8.3," T30 = ",F8.3,
     *" T40 = ",F8.3,/1X,"  T74 = ",F8.3," T75 = ",F8.3,
     *" T76 = ",F8.3," T77 = ",F8.3," T81 = ",F8.3//1X,
     *,"TOT REQUIRED = ",F10.3)
2001  FORMAT(1X,//" TASK TIMES ACCOMPLISHED "//"  T2 = ",F8.3,
     *" T3 = ",F8.3," T4 = ",F8.3," T5 = ",F8.3," T6 = ",
     *F8.3," T7 = ",F8.3," T8= ",F8.3," T9 = ",F8.3)
2002  FORMAT(1X," T11 = ",F8.3," T12 = ",F8.3," T13 = ",F8.3,
     *" T14 = ",F8.3," T19 = ",F8.3," T22 = ",F8.3," T30 = ",
     *F8.3," T40 = ",F8.3)
2003  FORMAT(1X," T74 = ",F8.3," T75 = ",F8.3," T76 = ",
     *F8.3," T77 = ",F8.3," T81 = ",F8.3//
     *" TOTAL TASK TIMES ACCOMPLISHED = ",F10.3)
3001  FORMAT(1X,7F8.3/7F8.3/7F8.3/F10.3)
      RETURN
      END
C
C
C >> USER FUNCTION FOR FLIGHT PARAMETER ,ECM, OPS CHECK <<
C >> REQUIREMENTS                                       <<
C
      FUNCTION USERF(IFN)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,
     *MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
     *TNEXT,TNOW,XX(100)
      DIMENSION PROBV(300),RNVEC(300),PROBB(300),RNVECB(300)
      DATA TLASTCK,TLSTSND/2*0./
C >> THE NEXT 2 DATA STATEMENTS DEFINE THE AIRCRAFT CONTROL
C    INPUTS: RNVEC = SERVICE TIMES
C            PROBV = CUMMULATIVE PROBABILITY OF INPUT
C            RNVECB = TIME UNTIL NEXT INPUT
C            PROBB = CUMMULATIVE PROBABILITY OF TIME BETWEEN
C
      DATA RNVEC/.3,.4,.5,.6,.7,.8,.9,1.,1.1,1.2,1.3,1.4
     *,1.5,1.6,1.7,1.8,1.9,2.,2.1,2.2,2.3,2.4,2.5,2.6
     *,2.7,2.8,2.9,3.,3.1,3.2,3.3,3.4,3.5,3.6,3.8,3.9
     *,4.,4.2,4.4,4.5,4.6,5.2,5.3,5.4,5.9,6.8,6.9,7.
     *,7.4,7.4,8.3,13.9/,PROBV/.07
     *,.166,.229,.286,.345,.404,.456,.487,.52,.566,.605,.624
     *,.662,.688,.716,.738,.751,.766,.786,.81,.823,.836,.849,.856
     *,.867,.873,.88,.891,.902,.913,.917,.924,.926,.93,.939,.943
     *,.95,.956,.959,.961,.967,.972,.978,.983,.985,.987,.989,.991
     *,.993,.996,.998,1./
      DATA RNVECB/.3
     *,.4,.5,.6,.7,.8,.9,1.,1.1,1.2,1.3,1.4
     *,1.5,1.6,1.7,1.8,1.9,2.,2.1,2.2,2.3,2.4,2.5,2.6
     *,2.7,2.8,2.9,3.,3.1,3.2,3.3,3.4,3.5,3.6,3.8,3.9
     *,4.,4.1,4.2,4.3,4.4,4.5,4.6,4.8,4.9,5.3,5.6,5.9
     *,6.,6.1,6.2,6.4,6.5,7.,7.2,7.3,7.4,8.7,10.7,11.2
```

```
     *,11.9,12.3/,PROBB/.059
     *,.112,.171,.263,.329,.420,.458,.511,.546,.581,.603,.6[illegible]
     *,.66,.684,.706,.724,.748,.761,.776,.796,.814,.827,.836,.849
     *,.855,.86,.868,.882,.888,.893,.897,.904,.908,.912,.917,.919
     *,.923,.93,.932,.936,.943,.945,.947,.95,.952,.956,.958,.961
     *,.965,.967,.969,.971,.974,.98,.985,.987,.989,.991,.993,.996
     *,.998,1./
C
      GO TO (1,2,3,4),IFN
C
C >> DETERMINE THE FLIGHT CONTROL PARAMETERS <<
C
1     J=1
      Z=DRAND(3)
C >> IF THE GENERATED RANDOM NUMBER IS LESS THAN THE
C    CUM. PROB. AT THAT STEP TAKE THE ASSOCIATED INPUT
20    IF(Z.LE.PROBV(J)) GO TO 10
      J=J+1
      GO TO 20
10    USERF=RNVEC(J)
      ZZ=DRAND(4)
      JJ=1
C >> IF THE GENERATED RANDOM NUMBER IS LESS THAN THE
C    CUM, PROB. AT THAT STEP TAKE THE ASSOCIATED INPUT
40    IF(ZZ.LE.PROBB(JJ)) GO TO 30
      JJ=JJ+1
      GO TO 40
30    XX(62)=RNVECB(JJ)
      RETURN
C
C >> USER FUNCTION FOR THE TYPE AND SERVICE TIMES ON ECM TASKS <<
C
2     ECMREQ=DRAND(7)
C >> 17% OF THE ECM TASKS REQUIRE POD CONTROL SWITCH CHANGES <<
      IF(ECMREQ.LE..17) USERF=RNORM(4.2,1.05,7)
C >> 26% OF THE ECM TASKS REQUIRE ALE-40 ACTIONS (FLARE OR
C      CHAFF DISPENSING)  AND  NOTING THE SIGNAL ON RWR SCOPE <<
      IF(ECMREQ.GT..17.AND.ECMREQ.LE..43)USERF=RNORM(1.7,.6,7)
C >> 57% OF THE ECM TASKS REQUIRE ONLY NOTING THE SIGNAL
C    ON THE RWR SCOPE      <<
      IF(ECMREQ.GT..43) USERF=RNORM(.6,.2,7)
102   RETURN
C
C >> WHEN LESS THAN 2 TASKS ARE TO BE SERVICED (ONE OF WHICH
C    IS IN SERVICE) DO AN "OPS CHECK" IF ONE HAS NOT BEEN
C    DONE IN THE LAST 5 MINUTES <<
3     IF(NNQ(3).GT.1.)GO TO 105
C >> DETERMINE THE TIME SINCE THE LAST "OPS CHECK" <<
C      TLASTCK = TIME LAST OPS CHECK COMPLETED
C       TLASTSND = TIME LAST OPS CHECK SENT TO QUEUE
      SPAN=TNOW-TLASTCK
      WHEN=TNOW-TLSTSND
C >> TEST TO SEE IF "OPS CHECK" IS REQUIRED <<
      IF(SPAN.GT.300.AND.WHEN.GT.300.) GO TO 103
```

```
C >> IF NO "OPS CHECK" REQUIRED SET USERF=0. <<
105   USERF=0.
      RETURN
C
C >> SET SWITCH REQUIRING THE OPS CHECK <<
103   USERF=1.
      TLSTSND=TNOW
      RETURN
C
C >> USER FUNCTION TO MARK TIME OF LAST "OPS CHECK" COMPLETION <<
4     USERF=0.
      TLASTCK=TNOW
      RETURN
C
      END

GEN,GROVES,LOWLVL,01/14/81,22;
LIMITS,4,6,140;

;    << NEGATIVE SEEDS FOR ANTITHETIC VARIANCE >>

;    << RANK TASKS BY PRIORITY(ATRIB(3)) - HIGHEST FIRST >>
;    << IF TASKS HAVE SAME ATRIB(3) PUT OLDEST FIRST >>
PRIORITYY/1,HVF(3)/2,HVF(3)/3,HVF(3)/NCLNR,LVF(JEVNT);
NETWORK;
;    << RESOURCE FOR SHORT TERM MEMORY- MULTIPLE SERVICE SCHEME >>
;    << RESOURCE FOR PILOT- SERVER                               >>
      RESOURCE/STMEM(2),1;
      RESOURCE/PILOT(1),2,3;
;    << START THE NAVIGATION LEG >>
STRT  CREATE;

;    << INITIATE TASKS REQUIRED AT THE TURN POINT >>
          ACT,,,TURN;
          ACT,,,SNPSR;
          ACT,,,CCLK;
          ACT,,,CHDG;
          ACT,,,CSPD;
          ACT,,,CALT;
          ACT,,,CCNAV;
          ACT,,,CLCDT;
          ACT,,,CFUEL;
          ACT,,,THRTL;
;
;    << THIS DETERMINES THE LEG TIME LESS 120 SECONDS >>
          ACT,RNORM(300.,90.,5),,NVLCT;


;
;    << DELAY INITIATION OF LOPING INPUTS FOR 1 SEC TO >>
;    << INSURE LOOP PARAMETERS HAVE BEEN SET           >>
          ACT,1.,,STECM;
          ACT,1.,XX(1).NE.1.,FRST;
;
;    << SET THE THREAT LEVEL BASED ON THE NAV LEG/FEBE TIME >>
```

```
;
;    << ECM ACTIVITY LEVEL SELECTION >>
THRTL  ASSIGN,XX(79)=XX(79)+1.;
         ACT,,XX(79).EQ.1.,LVLOW;
         ACT,,XX(79).EQ.2.,LVMED;
         ACT,,XX(79).EQ.3.,LVVHI;
         ACT,,XX(79).GE.4.,LVHI;
LVLOW ASSIGN,XX(71)=420.,XX(73)=0.;
         ACT,,,HALT;
LVMED ASSIGN,XX(71)=210.,XX(73)=0.;
         ACT,,,HALT;
LVVHI ASSIGN,XX(71)=20.,XX(73)=.13;
         ACT,210.
      ASSIGN,XX(71)=52.5;
         ACT,,,HALT;
LVHI  ASSIGN,XX(71)=52.5,XX(73)=0.;
         ACT,,,HALT;
;

;    << START ECM LOOP >>
STECM ASSIGN,ATRIB(1)=999.,ATRIB(2)=XX(79);
         ACT,,,ECM;

;    << INITIATE REOCCURING TASK SEQUENCES ON THE FIRST LEG >>
FRST  ASSIGN,XX(1)=1.;
         ACT,,,ACCLT;
         ACT,,,SYSPR;
;
;    << THE NAV LEG IS NOW 120 SECONDS FROM COMPLETION >>
NVLGT GOON;
         ACT;
;    << IF APPROACHING THE END OF LEG 2 INITIATE A FENCE CHECK >>
         ACT,,XX(79).EQ.2.,FNCE;

;    << SET THE SWITCH TO STOP THE NAV POINT SEARCH ROUTINE >>
      ASSIGN,XX(23)=1.;

;    << COMPLETE THIS NAV LEG AND START THE NEXT LEG >>
         ACT,120.,,STRT;

;    << INITIATE THE TASKS REQUIRED WHEN APPROACHING A TURN POINT >>
         ACT,90.,,UPINS;
         ACT,,,CNHDG;
         ACT,,,TRPTR;

; <>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
; < ALL ASSIGN NODES THAT ASSIGN ATRIBS 1,2 & 3 ARE ASSIGNING  >
; < TASK CODES,SERVICE TIMES AND PRIORITIES RESPECTIVELY       >
; < ATRIB(4) = A SERVICE INDICATOR FOR MULTIPLE SWITCHING      >
; < BETWEEN TASKS....INDICATOR VALUES DEFINED BELOW            >
; <   0.-NOT SPECIFIED DIVIDE BASED ON SERVE TIME              >
; <   1.-DO NOT DIVIDE SERVE TIME                              >
; <   2.-DIVIDE SERVE TIME INTO 2 PARTS                        >
; <   3.-DIVIDE SERVE TIME INTO 3 PARTS                        >
```

```
; <   4.-DIVIDE SERVE TIME INTO 4 PARTS                    >
; <   5.-DIVIDE SERVE TIME INTO 5 PARTS                    >
; <>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>

;    << CHECK CLOCK TASK >>
CCLK  GOON;
         ACT;
      ASSIGN,ATRIB(1)=2.,ATRIB(2)=RNORM(.6,.2,7),ATRIB(3)=3.,
       ATRIB(4)=1.,1;

;    << IF SWITCH IS SET SEND TASK TO COLCT NODE >>
         ACT/51,,XX(2).EQ.1.,TODO;
         ACT;

;    << SET THE SWITCH TO PREVENT MULTIPLES OF THIS TASK IN THE Q >>
      ASSIGN,XX(2)=1.;
         ACT/2,,,TASKQ;

;    << CROSSCHECK AIRCRAFT HEADING TASK >>
CHDG  GOON;
         ACT;
      ASSIGN,ATRIB(1)=3.,ATRIB(2)=RNORM(1.8,.6,7),ATRIB(3)=3.,
       ATRIB(4)=1.,1;

;    << IF SWITCH IS SET SEND TASK TO COLCT NODE >>
         ACT/53,,XX(3).EQ.1.,TODO;
         ACT;

;    << SET THE SWITCH TO PREVENT MULTIPLES OF THIS TASK IN THE Q >>
      ASSIGN,XX(3)=1.;
         ACT/3,,,TASKQ;

;    << CROSSCHECK AIRCRAFT SPEED TASK >>
CSPD  GOON;
         ACT;
      ASSIGN,ATRIB(1)=4.,ATRIB(2)=RNORM(1.8,.6,7),ATRIB(3)=2.,
       ATRIB(4)=1.,1;

;    << IF SWITCH IS SET SEND TASK TO COLCT NODE >>
         ACT/54,,XX(4).EQ.1.,TODO;
         ACT;

;    << SET THE SWITCH TO PREVENT MULTIPLES OF THIS TASK IN THE Q >>
      ASSIGN,XX(4)=1.;
         ACT/4,,,TASKQ;

;    << CROSSCHECK AIRCRAFT ALTITUDE TASK >>
CALT  GOON;
         ACT;
      ASSIGN,ATRIB(1)=5.,ATRIB(2)=RNORM(1.8,.6,7),ATRIB(3)=3.,
       ATRIB(4)=1.,1;

;    << IF SWITCH IS SET SEND TASK TO COLCT NODE >>
         ACT/55,,XX(5).EQ.1.,TODO;
```

```
          ACT;

;    << SET THE SWITCH TO PREVENT MULTIPLES OF THIS TASK IN THE Q >>
      ASSIGN,XX(5)=1.;
          ACT/5,,,TASKQ;

;    << CHECK NAV LEG TIME TASK >>
CCNAV GOON;
          ACT;
      ASSIGN,ATRIB(1)=6.,ATRIB(2)=RNORM(1.8,.6,7),ATRIB(3)=1.,
              ATRIB(4)=1.,1;

;    << IF SWITCH IS SET SEND TASK TO COLCT NODE >>
          ACT/56,,XX(6).EQ.1.,TODO;
          ACT;

;    << SET THE SWITCH TO PREVENT MULTIPLES OF THIS TASK IN THE Q >>
      ASSIGN,XX(6)=1.;
          ACT/6,,,TASKQ;

;    << CROSSCHECK NAV LEG DISTANCE TASK >>
CLGDT GOON;
          ACT;
      ASSIGN,ATRIB(1)=7.,ATRIB(2)=RNORM(.6,.2,7),ATRIB(3)=1.,
       ATRIB(4)=1.,1;

;    << IF SWITCH IS SET SEND TASK TO COLCT NODE >>
          ACT/57,,XX(7).EQ.1.,TODO;
          ACT;

;    << SET THE SWITCH TO PREVENT MULTIPLES OF THIS TASK IN THE Q >>
      ASSIGN,XX(7)=1.;
          ACT/7,,,TASKQ;

;    << CHECK FUEL TASK >>
CFUEL GOON;
          ACT;
      ASSIGN,ATRIB(1)=8.,ATRIB(2)=RNORM(.6,.2,7),ATRIB(3)=2.,
       ATRIB(4)=1.,1;

;    << IF SWITCH IS SET SEND TASK TO COLCT NODE >>
          ACT/58,,XX(8).EQ.1.,TODO;
          ACT;

;    << SET THE SWITCH TO PREVENT MULTIPLES OF THIS TASK IN THE Q >>
      ASSIGN,XX(8)=1.;
          ACT/8,,,TASKQ;

;    << UPDATE INS CO-ORDINATES TASK >>
UPINS GOON;
          ACT;
      ASSIGN,ATRIB(1)=9.,ATRIB(2)=RNORM(10.,2.,8),ATRIB(3)=3.,
              ATRIB(4)=0.,1;
```

```
;    << IF SWITCH IS SET SEND TASK TO COLCT NODE >>
          ACT/59,,XX(9).EQ.1.,TODO;
          ACT;

;    << SET THE SWITCH TO PREVENT MULTIPLES OF THIS TASK IN THE Q >>
       ASSIGN,XX(9)=1.;
           ACT/9,,,TASKQ;
;
;    <<CHECK INS ACCURACY TASK >>
CKINS GOON;
           ACT;
       ASSIGN,ATRIB(1)=11.,ATRIB(2)=RNORM(3.,.5,4),ATRIB(3)=4.,
        ATRIB(4)=1.,1;

;    << IF SWITCH IS SET SEND TASK TO COLCT NODE >>
           ACT/61,,XX(11).EQ.1.,TODO;
           ACT;

;    << SET THE SWITCH TO PREVENT MULTIPLES OF THIS TASK IN THE Q >>
       ASSIGN,XX(11)=1.;
           ACT/11,,,TASKQ;
;
;    << CROSSCHECK NEXT HDG ON CHART TASK >>
CNHDG GOON;
           ACT;
       ASSIGN,ATRIB(1)=12.,ATRIB(2)=RNORM(1.8,.6,7),ATRIB(3)=4.,
        ATRIB(4)=1.,1;

;    << IF SWITCH IS SET SEND TASK TO COLCT NODE >>
           ACT/62,,XX(12).EQ.1.,TODO;
           ACT;

;    << SET THE SWITCH TO PREVENT MULTIPLES OF THIS TASK IN THE Q >>
       ASSIGN,XX(12)=1.;
           ACT/12,,,TASKQ;
;
;    << REVIEW TURN PT ON CHART TASK >>
TRPTR GOON;
           ACT;
       ASSIGN,ATRIB(1)=13.,ATRIB(2)=RNORM(6.,1.5,9),ATRIB(3)=3.,
             ATRIB(4)=0.,1;

;    << IF SWITCH IS SET SEND TASK TO COLCT NODE >>
           ACT/63,,XX(13).EQ.1.,TODO;
           ACT;

;    << SET THE SWITCH TO PREVENT MULTIPLES OF THIS TASK IN THE Q >>
       ASSIGN,XX(13)=1.;
           ACT/13,,,TASKQ;

;    << CHANGE IFF CODE >>
CIFF  CREATE,,0.;
           ACT;
```

```
      ASSIGN,ATRIB(1)=14.,ATRIB(2)=RNORM(6.6,.76,7),ATRIB(3)=7.,
           ATRIB(4)=1.;
         ACT/14,UNFRM(0.,1800.,7),,TASKQ;

;    << OPS CHECK TASK PARAMETERS >>
SYSPR ASSIGN,ATRIB(1)=19.,ATRIB(2)=RNORM(3.,.5,7),ATRIB(3)=3.,
           ATRIB(4)=3.,1;
;
         ACT/69,,XX(19).EQ.1.,TODO;
;    << SET SWITCH TO PREVENT MULTIPLES OF THIS TASK IN THE Q >>
         ACT;
      ASSIGN,XX(19)=1.;
;
         ACT/19,,,TASKQ;
;
;    << MARK COMPLETION OF OPS CHECK >>
SYSLC ASSIGN,XX(55)=USERF(4);
         ACT,,,HALT;
;    << RELEASE THE SWITCH TO ALLOW THE NAV POINT SEARCH ROUTINE >>
SNPSR ASSIGN,XX(23)=0.,ATRIB(1)=XX(79);
         ACT;

;    << NAV POINT SEARCH ROUTINE >>
NPSRH GOON,1;
;   << STOP NAV SEARCH ROUTINES FROM PREVIUOS LEGS >>
         ACT,,ATRIB(1).EQ.XX(79);
         ACT,,,HALT;
      GOON

;    << LOOK FOR A NAV POINT EVERY 240 SECONDS >>
         ACT,RNORM(240.,15.,7),XX(23).EQ.0.,NPSRH;

;    << DON'T ALLOW A NAV PT SEARCH WITHIN 120 SEC OF NEXT TURN PT >>
         ACT,,XX(23).EQ.1.,HALT;
         ACT,,XX(23).EQ.0.;
      ASSIGN,ATRIB(1)=22.,ATRIB(2)=RNORM(6.,1.5,2),ATRIB(3)=4.,
           ATRIB(4)=0.,2;
         ACT,,,CKINS;

;    << DON'T ALLOW ANOTHER SEARCH TASK IN THE Q UNTIL THE >>
;    << LAST ONE IS COMPLETED                              >>

;    << IF SWITCH IS SET SEND TASK TO COLCT NODE THROUGH NVSW >>
         ACT,,XX(22).EQ.1,NVSW;
         ACT;

;    << SET THE SWITCH TO PREVENT MULTIPLES OF THIS TASK IN THE Q >>
      ASSIGN,XX(22)=1.;
         ACT/22,,,TASKQ;
;
;    << SET NAV POINT SWITCH TO "NSEEN" IF NAV POINT SEARCH >>
;    << TASK WAS NOT ACCOMPLISHED WHEN A NEW ONE WAS DUE    >>
NVSW  ASSIGN,XX(21)=0.;
         ACT/64,,,TODO;
```

```
;
SEEPT EVENT,2;
        ACT,,,HALT;
;
;    << AIRCRAFT CONTROL TASK >>
ACCLT GOON
        ACT;
      ASSIGN,ATRIB(1)=30.,ATRIB(2)=USERF(1),ATRIB(3)=7.,
           ATRIB(4)=1.;
        ACT/30,,,CRITT;
        ACT,ATRIB(2);
      GOON;
        ACT,XX(62),,ACCLT;

;    << TURN TO NEW HEADING TASK >>
TURN  GOON;
        ACT;
      ASSIGN,ATRIB(1)=40.,ATRIB(2)=RNORM(18.,9.,1),ATRIB(3)=8.,
           ATRIB(4)=1.;
        ACT/40,,,CRITT;

;    << FENCE CHECK TASK >>;
FNCE  ASSIGN,ATRIB(1)=74.,ATRIB(2)=RNORM(20.5,7.52,7),ATRIB(3)=5.,
       ATRIB(4)=0.;
        ACT,,,TASKQ;
;
;    << DEFENSIVE MANEUVER TASK  >>
;    << DEFENSIVE MANEUVER AND SET STRESS SWITCH FOR THE >>
;    << DEFENSIVE MANEUVER                               >>
DEFM  GOON;
;
        ACT;
      ASSIGN,XX(75)=XX(75)+1.;
        ACT,,,MANV;
;
;    << AFTER 10 MIN. STRESS FROM DEFENSIVE MANEUVER IS GONE >>
        ACT,600.,,SADJ;
SADJ  ASSIGN,XX(75)=XX(75)-1.;
        ACT,,,HALT;
MANV  ASSIGN,ATRIB(1)=75.,ATRIB(2)=RNORM(30.,5.,5),ATRIB(3)=9.,
           ATRIB(4)=1.;
        ACT/75,,,CRITT;

;    << ECM TASK >>
ECMLS ASSIGN,ATRIB(1)=6.;
        ACT;
ECM   GOON,1;
;    << STOP THE LOOP OF PREVIOUS LEGS >>
        ACT,,ATRIB(2).NE.XX(79),HALT;
        ACT;
;    << NOTE THE LEG THE INTITY WAS GERERATED ON >>
      ASSIGN,ATRIB(2)=XX(79);
        ACT,EXPON(XX(71),6),,ECMLS;
;    << LET SERVICE OF THE TASK DIE IF IT IS A LOOP STARTER >>
```

```
         ACT,,ATRIB(1).NE.999.;
ECMPR ASSIGN,ATRIB(1)=76.,ATRIB(2)=USERF(2),ATRIB(3)=7.,
             ATRIB(4)=2.,XX(74)=DRAND(7);
;    << TEST TO SEE IF A DEFENSIVE MANEUVER IS REQUIRED >>
         ACT,,XX(74).LT.XX(73),DEFM;
         ACT/76,,,TASKQ;
;    << SET THE ECM STRESS FACTOR >>
         ACT,,,ECMSF;
;
;    << ADJUST STRESS FACTOR FOR ECM INPUTS >>
ECMSF ASSIGN,XX(76) = XX(76) + ATRIB(2);
         ACT,120.
      ASSIGN,XX(76) = XX(76)- ATRIB(2);
         ACT,,,HALT;

;    << FUEL SWITCHING TASK >>
GASW  CREATE,,0.,1;
         ACT;
      ASSIGN,ATRIB(1)=81.,ATRIB(2)=RNORM(1.1,.76,7),ATRIB(3)=4.,
             ATRIB(4)=1.;
         ACT/81,RNORM(900.,100.,7),,TASKQ;

;    <<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
;    << QUEUEING SYSTEM FOR AIRCRAFT CONTROL, TURN AND >>
;    << DEFENSIVE MANEUVER TASKS                                >>
;    <<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
CRITT GOON;
         ACT;
         ACT,,,TODO;
      PREEMPT(2)/HIGH(3),PILOT,,6;
         ACT;
;    << CHECK FOR THE PROBABILITY OF AN ERROR DUE TO >>
;    << STRESS--IF ERROR SEND TWO TASKS BACK FOR      >>
;    << SERVICE--ONE TO CORRECT ERROR AND ONE TO APPLY >>
;    << THE PROPER CONTROL INPUT                       >>
      EVENT,1;
         ACT;
SKIP  ASSIGN,XX(96)=DRAND(7),XX(78)=XX(97)-.03;
         ACT,,XX(96).LT.XX(78),CRITT;
         ACT,,XX(96).LT.XX(78),CRITT;
         ACT/31,ATRIB(2),,RELC;
         ACT;
      ASSIGN,ATRIB(2)=ATRIB(2)-.001,1;
         ACT,ATRIB(2),ATRIB(1).EQ.40..OR.ATRIB(1).EQ.75.,ADJCT;
         ACT,,,HALT;
;    << TASK QUEUE >>
;
;    << RESOURCE STMEM (SHORT TERM MEMORY) ALLOWS 2 TASKS IN >>
;    << THE MULTIPROCESSING SCHEME AT ONE TIME               >>
TASKQ GOON;
         ACT,,,TODO;
         ACT;
        AWAIT(1),STMEM;
         ACT,,,STRSS;
```

```
;
;    << REACCOMPLISH TASKS BASED ON STRESS TEST >>
STRSS EVENT,1,1;
         ACT;
OUT   ASSIGN,XX(96)=DRAND(7);
;    << IF THE RANDOM NUMBER IS LESS THAN THE STRESS >>
;    << TOTAL [XX(97)] REACCOMPLISH THE TASK        >>
         ACT,,XX(96).LT.XX(97),TASKQ;
         ACT;
      COON,1;
;
;    << MULTIPLE SWITCHING BETWEEN TASKS SCHEME >>
;
;    << ATRIB(4) INDICATES MULTIPLE SERVICE SPECIFICATIONS >>
         ACT,,ATRIB(4).EQ.1.,ASG1;
         ACT,,ATRIB(4).EQ.2.,ASG2;
         ACT,,ATRIB(4).EQ.3.,ASG3;
;
;    << IF MULTIPLE SERVICE SCHEME IS NOT SPECIFIED BREAK THE >>
;    << SERVICE UP BASED ON TASK TIME                         >>
         ACT,,ATRIB(2).LE.3.,ASG1;
         ACT,,ATRIB(2).LE.6.,ASG2;
         ACT,,ATRIB(2).LE.12.,ASG3;
         ACT,,ATRIB(2).LE.24.,ASG4;
         ACT,,ATRIB(2).GT.24.,ASG5;
;
;    << ATRIB(5) = NUMBER OF TIMES THE TASK MUST BE PROCESSED >>
;    << TO COMPLETE THE SERVICE                               >>
ASG1  ASSIGN,ATRIB(5)=1.;
         ACT,,,SERVQ;
ASG2  ASSIGN,ATRIB(5)=2.,ATRIB(2)=ATRIB(2)/2.;
         ACT,,,SERVQ;
ASG3  ASSIGN,ATRIB(5)=3.,ATRIB(2)=ATRIB(2)/3.;
         ACT,,,SERVQ;
ASG4  ASSIGN,ATRIB(5)=4.,ATRIB(2)=ATRIB(2)/4.;
         ACT,,,SERVQ;
ASG5  ASSIGN,ATRIB(5)=5.,ATRIB(2)=ATRIB(2)/5.;
         ACT,,,SERVQ;
;
;    << TASKS ARE SERVICED SERIALLY BY RESOURCE PILOT >>
SERVQ ASSIGN,ATRIB(6)=ATRIB(2);
         ACT;
      AWAIT(3),PILOT;
         ACTIVITY/1,ATRIB(6),,REL;
REL   FREE,PILOT/1;
         ACT,,,ACOMP;
         ACT;
;
;    << ADJUST  AND CHECK SERVICE COUNTER AND       >>
;    << SEND IT BACK FOR MORE SERVICE IF REQUIRED   >>
;    << IF THE TASK IS COMPLETE ALLOW ANOTHER TASK  >>
;    << TO ENTER THE SERVICE SCHEME                 >>
ADJUST ASSIGN,ATRIB(5)=ATRIB(5)-1.,1;
         ACT,,ATRIB(5).GT.0.,SERVQ;
```

```
        ACT,,ATRIB(5).EQ.0.,MORE;
MORE  FREE,STMEM/1;
        ACT,,,SYSCK;
;
;    << IF COMPLETED TASK IS A OPS CHECK MARK THE COMPLETION TIME >>
        ACT,,ATRIB(1).EQ.19.,SYSLC;
;
;    << IF THE COMPLETED TASK IS A NAV POINT SEARCH >>
;    << CHECK SUCCESS OF THE NAV PT SEARCH          >>
        ACT,,ATRIB(1).EQ.22.,SEEPT;
;
;    << RELEASE RESOURCES THAT PREEMPTED OTHER TASKS >>
RELC  FREE,PILOT/1;
        ACT,,,ACOMP;
;
;    << REMOVE FLT CONT TASKS INPUT DURING TURNS>>
;    << & DEF MANEUVERS                          >>
ADJCT EVENT,3;
        ACT,,,HALT;
;
;    << DETERMINE IF AN OPS CHECK IS APPROPRIATE >>
SYSCK ASSIGN,XX(55)=USERF(3),2;
        ACT,,XX(55).EQ.1.,SYSPR;
;
;    << SEND COMPLETED TASKS TO RELEASE SWITCHES >>
        ACT,,ATRIB(1).EQ.2.,A02;
        ACT,,ATRIB(1).EQ.3.,A03;
        ACT,,ATRIB(1).EQ.4.,A04;
        ACT,,ATRIB(1).EQ.5.,A05;
        ACT,,ATRIB(1).EQ.6.,A06;
        ACT,,ATRIB(1).EQ.7.,A07;
        ACT,,ATRIB(1).EQ.8.,A08;
        ACT,,ATRIB(1).EQ.9.,A09;
        ACT,,ATRIB(1).EQ.11.,A11;
        ACT,,ATRIB(1).EQ.12.,A12;
        ACT,,ATRIB(1).EQ.13.,A13;
        ACT,,ATRIB(1).EQ.19.,A19;
        ACT,,ATRIB(1).EQ.22.,A22;
;
;    <. CHECK SUCCESS OF THE NAV POINT SEARCH >>
;    << SUM THE SERVICE TIMES OF ALL TASKS PRESENTED >>
TODO  EVENT,5;
        ACT,,,HALT;
;
;    << SUM THE SERVICE TIMES OF ALL TASKS ACCOMPLISHED >>
ACOMP EVENT,4;
        ACT;
HALT  TERMINATE;

;    << THESE NODES RELEASE THE NO MULTIPLE TASK SWITCHES >>
A02   ASSIGN,XX(2)=0.;
        ACT,,,STOP;
A03   ASSIGN,XX(3)=0.;
        ACT,,,STOP;
```

```
A04   ASSIGN,XX(4)=0.;
         ACT,,,STOP;
A05   ASSIGN,XX(5)=0.;
         ACT,,,STOP;
A06   ASSIGN,XX(6)=0.;
         ACT,,,STOP;
A07   ASSIGN,XX(7)=0.;
         ACT,,,STOP;
A08   ASSIGN,XX(8)=0.;
         ACT,,,STOP;
A09   ASSIGN,XX(9)=0.;
         ACT,,,STOP;
A11   ASSIGN,XX(11)=0.;
         ACT,,,STOP;
A12   ASSIGN,XX(12)=0.;
         ACT,,,STOP;
A13   ASSIGN,XX(13)=0.;
         ACT,,,STOP;
A19   ASSIGN,XX(19)=0.;
         ACT,,,STOP;
A22   ASSIGN,XX(22)=0.;
         ACT,,,STOP;
STOP  TERMINATE;
      ENDNETWORK;
;
;    << RUN LENGTH >>
INIT,0.,1800.;
;
;    << INITIALIZE PARAMETERS FOR FUEL SWITCHING AND >>
;    << STRESS SWITCHES FOR DEF MANVS, SYS MAL AND   >>
;    << NAV POINT SEARCH SUCCESS                     >>
INTLC,XX(75)=0.,XX(1)=0.,XX(76)=0.,XX(21)=1.,XX(79)=0.;
;    << NEGATIVE SEEDS FOR HALF TOTAL RUNS & POSITIVE >>
;    << SEEDS FOR THE REMAINDER TO USE ANTITHETIC     >>
;    << REDUCTION TECHNIQUE                           >>
SEEDS,-69578,-40961,-93969,-61129,-43211,-97336,
      -67584,-12265,-21382,-54092;
SIMULATE
SIMULATE
SIMULATE
SIMULATE
SIMULATE
SIMULATE
SIMULATE
SIMULATE
SIMULATE
SIMULATE
SIMULATE
SEEDS,69578,40961,93969,61129,43211,97336,
      67584,12265,21382,54092;
FIN;
```

Appendix C

Distribution Tests

This appendix contains six statistical tests that were used to confirm the results of the input distributions specified in the model. Six Kolmogorov-Smirnov tests were used to test the distributions for navigation leg lengths, navigation point search spacing, navigation task service times, turn service times, and flight control task times.

Leg Length

H_0: The leg lengths are from a Normal (420.,90.) distribution.

H_1: The leg lengths are not from a Normal (420.,90.) distribution.

```
- - - - - KOLMOGOROV - SMIRNOV GOODNESS OF FIT TEST

   TIME

TEST DIST. - NORMAL (MEAN =     420.0000 STD. DEV. =     90.0000)

        CASES     MAX(ABS DIFF)     MAX(+ DIFF)     MAX(- DIFF)
          4          .4911            .4911           -.2303

        K-S Z       2-TAILED P
        .982          .289
```

.624 > .4911; therefore, fail to reject H_0 at alpha equal to .05.

Time Between Nav Points

H_0: The time between searching for nav points is from a Normal (240.,15.) distribution.

H_1 The time between searching for nav points is not from a Normal (240.,15.) distribution.

```
- - - - - KOLMOGOROV - SMIRNOV GOODNESS OF FIT TEST

   TIME

ST DIST. - NORMAL (MEAN =     240.0000 STD. DEV. =     15.0000)

        CASES     MAX(ABS DIFF)     MAX(+ DIFF)     MAX(- DIFF)
          11         .3220            .2138           -.3220

        K-S Z       2-TAILED P
        1.068         .204
```

.391 > .3220; therefore, fail to reject H_0 at alpha equal to .05.

Navigation Service Times

H_0: The time required to find a nav point once search begins is from a Normal (6.,1.5) distribution.

H_1: The time required to find a nav point once search begins is not from a Normal (6.,1.5) distribution.

```
- - - - - KOLMOGOROV - SMIRNOV GOODNESS OF FIT TEST

   TIME

TEST DIST. - NORMAL (MEAN =      6.0000 STD. DEV. =      1.5000)

          CASES     MAX(ABS DIFF)     MAX(+ DIFF)     MAX(- DIFF)
           12          .1507             .1476          -.1507

          K-S Z       2-TAILED P
          .522          .948
```

.375 > .1507; therefore, fail to reject H_0 at alpha equal to .05.

Turn Servicing Time

H_0: The time required to complete a turn is from a Normal (18.9.) distribution.

H_1: The time required to complete a turn is not from a Normal (18.,9.) distribution.

```
- - - - KOLMOGOROV - SMIRNOV GOODNESS OF FIT TEST

   TIME

TEST DIST. - NORMAL (MEAN =      18.0000 STD. DEV. =      9.0000)

          CASES     MAX(ABS DIFF)     MAX(+ DIFF)     MAX(- DIFF)
            5          .3622             .3622          -.2331

          K-S Z       2-TAILED P
          .810          .528
```

.565 > .3622; therefore, fail to reject H_0 at alpha equal to .05.

Flight Control Movements

H_0: The periods of flight control movements are from the empirical data used in the program for movement periods.

H_1: The periods of flight control movements are not from the empirical data used in the program for movement periods.

```
=      1.      =      2. MAX(ABS DIFF)   MAX(+ DIFF)   MAX(- DIFF)
      458            66         .1060         .1080        -.0308

      K-S Z     2-TAILED P
      .821        .511
```

.1274 > .1080; therefore, fail to reject H_0 at alpha equal to .05.

Flight Control Non-Movements

H_0: The periods of flight control non-movements are from the empirical data used in the program for non-movement periods.

H_1: The periods of flight control non-movements are not from the empirical data used in the program for non-movement periods.

```
=      1.      =      2. MAX(ABS DIFF)   MAX(+ DIFF)   MAX(- DIFF)
      458            20         .1793         .1793        -.0400

      K-S Z     2-TAILED P
      .785        .569
```

.2026 > .1793; therefore, fail to reject H_0 at alpha equal to .05.

Appendix D

ECM Task Initiation Data

This appendix contains a table of the data determined from the threat array model.

DEFENSIVE REACTION TASK INITIATION DATA

	P_k Range				
Altitude	A	B	C	D	Total*
1000	142 (57%)	64 (26%)	42 (17%)	32 (13%)	248 (100%)**
500	64 (38%)	97 (58%)	7 (4%)	1 (.5%)	168 (68%)**
250	42 (52%)	38 (46%)	2 (2%)	0 (0%)	82 (33%)**

*Total = A + B + C
A = .01 to .10
B = .10 to .20
C = .20 and greater
D = .30 and greater

**This percentage is the total for that altitude divided by the 1000 foot total.

Appendix E

FORTRAN Program for Aircraft Control Movements

This appendix contains the flow diagrams, FORTRAN code listing and an example verification run of the program used to reduce raw data of stick position to periods of movement and non-movement. Voltages for the verification run are in thousands because actual data was divided by ten before the results were recorded.

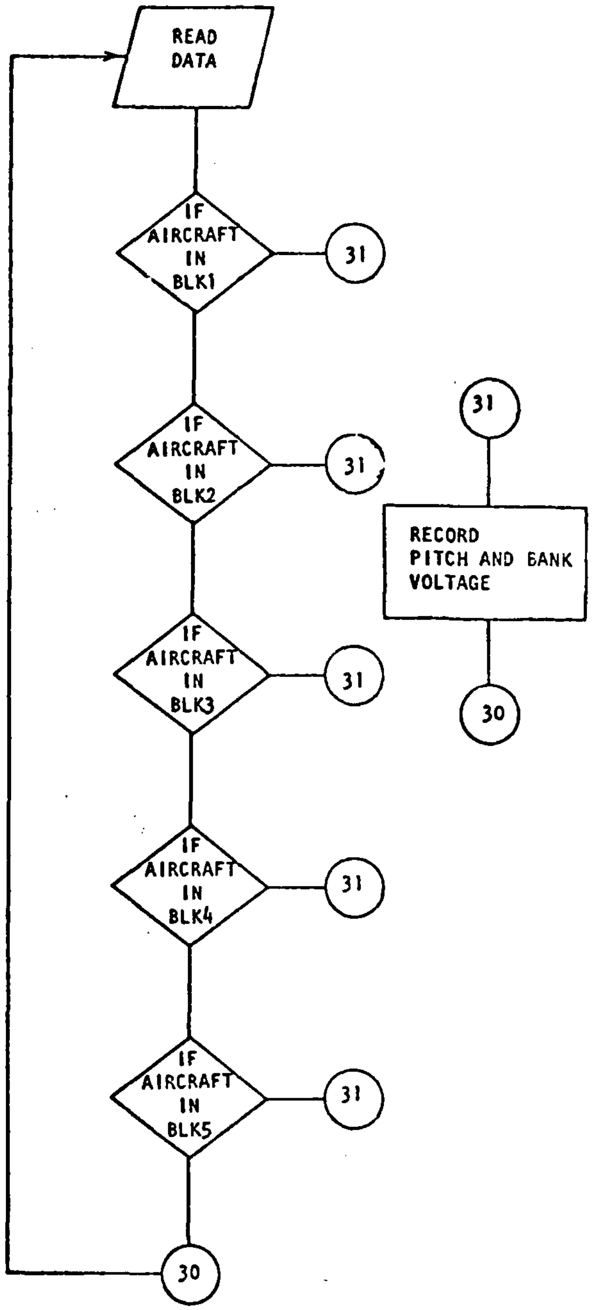


Fig. E-1. Flow Chart (Recorded Data Section)

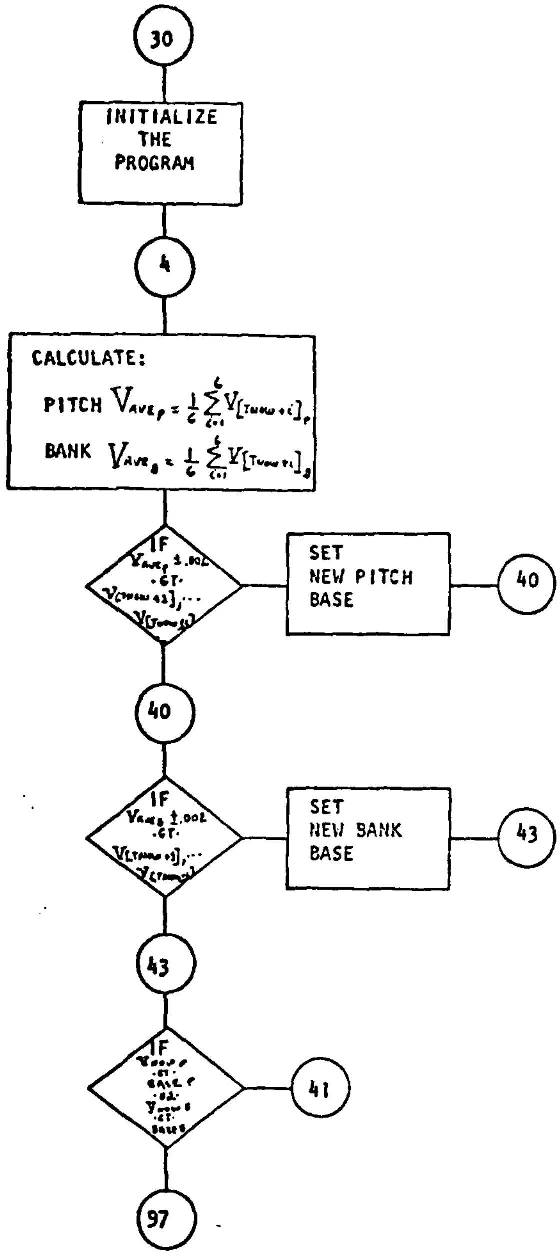


Fig. E-2. Flow Chart (Set Pitch and Bank Base)

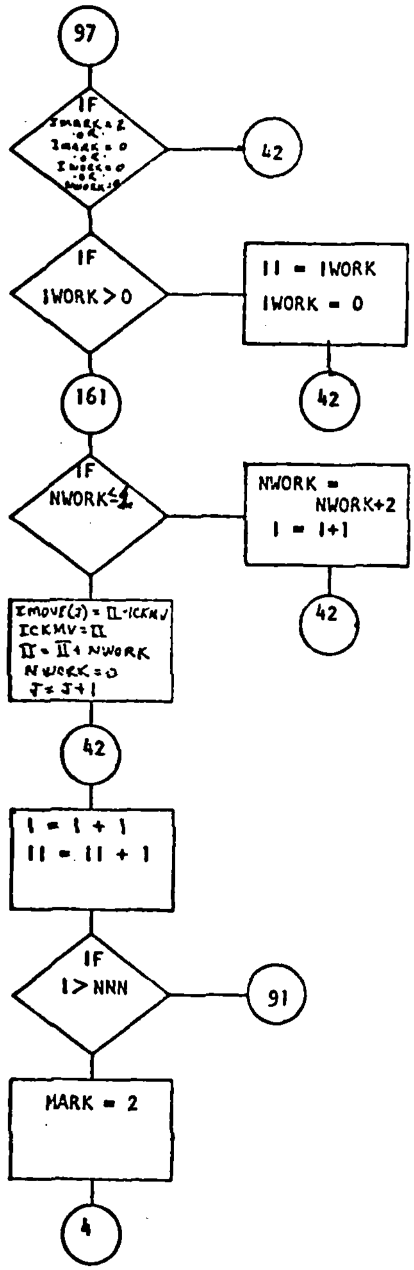


Fig. E-3. Flow Chart (No Stick Movements)

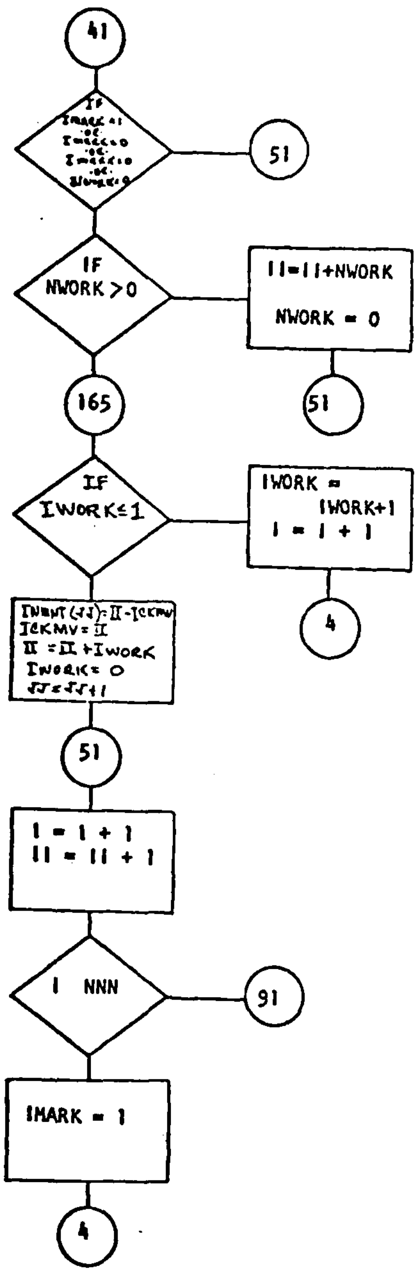


Fig. E-4. Flow Chart (Stick Movements)

```
      PROGRAM DISTRI (INPUT,OUTPUT,TAPE5,TAPE6,TAPE7)
      DIMENSION PSTIK(8020),INMNT(500),IMOVE(500),BSTI[illegible]
C
C
1001  FORMAT(10X,F9.5,1X,F10.5,15X,2F5.3)
1002  FORMAT(10(2X,I6))
C
      M=1
      NNN=0
C
C         ************************************************************
C
C         DO LOOP 30 READS DATA AND DETERMINES WHETHER OR NOT
C         AIRCRAFT IS IN A RECORD BLOCK,  NN CHANGES BASED ON
C         NUMBER OF DATA POINTS
C
C         ************************************************************
C
      NN=6900
      DO 30 I=1,NN
      READ(5,1001) ALAT,ALONG,BMOVE,PMOVE
      IF(ALAT.GT.(36.3166).AND.ALAT.LT.(36.45)
     *.AND.ALONG.GT.(-11.35).OR.
     *ALAT.GT.(36.5).AND.ALAT.LT.(36.65)
     *.AND.ALONG.GT.(-11.25).OR.
     *ALAT.GT.(36.6833).AND.ALAT.LT.(36.7333)
     *.AND.ALONG.GT.(-11.25).OR.
     *ALAT.GT.(36.66667).AND.
     *ALONG.GT.(-11.35).AND.ALONG.LT.(-11.26667).OR.
     *ALAT.GT.(36.25).AND.ALAT.LT.(36.65)
     *.AND.ALONG.LT.(-11.35833)) GO TO 31
      GO TO 30
31    BSTIK(M)=BMOVE
      PSTIK(M)=PMOVE
      M=M+1
30    CONTINUE
C
      KK=0
      KKK=0
C
      NNN=M-1
C
C         ************************************************************
C
C         J, TRACKS THE NUMBER OF MOVEMENTS IN THE DISTRIBUTION
C         JJ, TRACKS THE NUMBER OF NO MOVEMENTS IN THE DISTRIBUTION
C         II, RESETS THE COUNTER FOR TRACKING LENGTH OF MOVEMENT
C             AND LENGTH OF NON-MOVEMENT
C         IMARK, DEFINES WHETHER THE STRING BUILDING IS A MOVEMENT
C                OR  NON-MOVEMENT
```

```
C        IBASP, ESTABILISHES THE BASE FOR PITCH
C        IBASB, ESTABLISHES THE BASE FOR BANK
C        ICKMV, SERVES AS A POINT WHICH ESTABLISHES THE BEGINNING OF
C              MOVEMENT OR NON-MOVEMENT
C        PCEKU, UPPER LIMIT FOR CHECKING NEED FOR PITCH BASE CHANGE
C        PCEKL, LOSER LIMIT FOR CHECKING NEED FOR PITCH BASE CHANGE
C        BCEKU, UPPER LIMIT FOR CHECKING NEED FOR BANK BASE CHANGE
C        BCEKL, LOWER LIMIT FOR CHECKING NEED FOR BANK BASE CHANGE
C        PBODU, PITCH BASE BOUNDRY UPPER LIMIT
C        PBODL, PITCH BASE BOUNDRY LOWER LIMIT
C        BBODU, BANK BASE BOUNDRY UPPER LIMIT
C        BBODL, BANK BASE BOUNDRY LOWER LIMIT
C        IWORK, IDENTIFIES THE STRING BEING BUILT AS MOVEMENT
C        NWORK, IDENTRFIES THE STRING BEING BUILT AS NON-MOVEMENT
C
C        ****************************************************************
      J=1
      JJ=1
      II=0
      IMARK=0
      IBASP=0
      IBASB=0
      ICKMV=0
      PCEKU=0
      PCEKL=0
      BCEKU=0
      BCEKL=0


      PBODU=.002
      PBODL=-.002
      BBODU=.002
      BBODL=-.002
      IWORK=0
      NWORK=0
C
      NNN=NNN-6
      I=1
C
C
C       ****************************************************************
C
C        4 - START OF A LOOP WHICH CHECKS EACH PITCH AND BANK VOLTAGE
C            DETERMINES IF IT IS A MOVEMENT OR NON-MOVEMENT
C
C       ****************************************************************
C
4     PBILD=0
      BBILD=0
      IP=I+1
      IF(I.GT.NNN) GO TO 91
```

```
C
C       ########################################################
C        DETERMINE AVERAGE VOLTAGE FOR V(TNOW+1) THRU (V(TNOW+6)
C        IN PITCH AND BANK
C       ########################################################
C
      DO 110 K=1,6
      PBILD=PBILD+PSTIK(IP)
      BBILD=BBILD+BSTIK(IP)
      IP=IP+1
110   CONTINUE
      PCHEK=PBILD/6
      BCHEK=BBILD/6
      PCEKU=PCHEK+.002
      PCEKL=PCHEK-.002
      BCEKU=BCHEK+.002
      BCEKL=BCHEK-.002
C
C
      IP=I+1
C
C       ########################################################
C
C       DO LOOP 120 CHECKES FOR BASE CHANGE IN PITCH
C       DO LOOP 211 CHECKS FOR BASE CHANGE IN BANK
C
C       ########################################################
C
      DO 120 K=1,6
      IF(PSTIK(IP).GT.PCEKU.OR.PSTIK(IP).LT.PCEKL) GO TO 40
      IP=IP+1
120   CONTINUE
C
      IF(PBODU.EQ.PCEKU.AND.PBODL.EQ.PCEKL) GO TO 40
      PBODU=PCEKU
      PBODL=PCEKL
      IBASP=IBASP+1
C
40    IP=I+1
      DO 121 K=1,6
      IF(BSTIK(IP).GT.BCEKU.OR.BSTIK(IP).LT.BCEKL) GO TO 43
      IP=IP+1
121   CONTINUE
C
      IF(BBODU.EQ.BCEKU.AND.BBODL.EQ.BCEKL)GO TO 43
      BBODU=BCEKU
      BBODL=BCEKL
      IBASB=IBASB+1
C
```

```
C
C        ****************************************************************
C
C        THE FOLLOWING IF STATEMENT DETERMINES WHETHER OR NOT
C        THE STICK IS MOVING
C
C        ****************************************************************
43    IF(PSTIK(I).GT.PBODU.OR.PSTIK(I).LT.PBODL
     *.OR.BSTIK(I).GT.BBODU.OR.BSTIK(I).LT.BBODL) GO TO 41
C
C        **************************************************************
C
C        THE FOLLOWING SECTION TRACKS NON-MOVEMENT PERIODS
C
C        **************************************************************
C
      IF((IMARK.EQ.2.OR.IMARK.EQ.0)
     *.AND.(IWORK.EQ.0.AND.NWORK.EQ.0)) GO TO 42
C
      IF(IWORK.GT.0) GO TO 162
      GO TO 161
162   II=II+IWORK
      IWORK=0
      GO TO 42
C
161   IF(NWORK.LE.1) GO TO 46
      IMOVE(J)=II-ICKMV
      ICKMV=II
      II=II+NWORK
      NWORK=0
      J=J+1
42    I=I+1
      II=II+1
      IF(I.GT.NNN) GO TO 91
      IMARK=2
      GO TO 4
C
46    NWORK=NWORK+1
      I=I+1
      GO TO 4
C
```

```
C        ************************************************************
C
C        THE FOLLOWING SECTION TRACKS MOVEMENT PERIODS
C
C        ************************************************************
C
41    IF((IMARK.EQ.1.OR.IMARK.EQ.0)
     *.AND.(IWORK.EQ.0.AND.NWORK.EQ.0)) GO TO 51
C
      IF(NWORK.GT.0) GO TO 164
      GO TO 165
164   II=II+NWORK
      NWORK=0
      GO TO 51
C
165   IF(IWORK.LE.1) GO TO 47
      INMNT(JJ)=II-ICKMV
      ICKMV=II
      II=II+IWORK
      IWORK=0
      JJ=JJ+1
51    I=I+1
      II=II+1
      IF(I.GT.NNN) GO TO 91
      IMARK=1
      GO TO 4
C
47    IWORK=IWORK+1
      I=I+1
      GO TO 4
```

```
C
91    J=J-1
      JJ=JJ-1
      IBAL=II-ICKMV
      IA=0
      IB=0
      IAA=0
C
      DO 200 I=1,J
      IA=IA+IMOVE(I)
200   CONTINUE
      DO 210 I=1,JJ
      IB=IB+INMNT(I)
210   CONTINUE
C
      IAA=IA+IB
C
      PRINT*," "
      PRINT*," "
      PRINT*,"NUMBER OF TIMES THE PITCH BASE WAS CHANGED  =",IBASP
      PRINT*,"NUMBER OF TIMES THE BANK BASE WAS CHANGED  =",IBASB
      PRINT*," "
      PRINT*,"NUMBER OF PERIODS OF MOVEMENT   =",J
      PRINT*,"NUMBER OF PERIODS OF NO MOVEMENT  =",JJ
      PRINT*," "
      PRINT*,"NUMBER OF TENTHS OF SECONDS  = ",IAA
      PRINT*,"  "
      PRINT*," NUMBER OF TENTHS NOT ACCOUNTED FOR  =  ",IBAL
```

```
C
C
      KKK=J
      N=1
      K=10
C
      WRITE(6,*)"  250 FEET,  PILOT 3,MOVEMENTS"
C
80    WRITE(6,1002) (IMOVE(KK),KK=N,K)
      J=J-10
      N=N+10
      K=K+10
      IF(J.GE.10) GO TO 80
      IF(J.LT.10.AND.J.GE.0) GO TO 82
      GO TO 81
82    K=KKK
      GO TO 80
C
C
81    KKK=JJ
      WRITE(7,*)"  250 FEET,  PILOT 3  ,NO MOVEMENTS"
      N=1
      K=10
90    WRITE(7,1002) (INMNT(KK),KK=N,K)
      JJ=JJ-10
      N=N+10
      K=K+10
      IF(JJ.GE.10) GO TO 90
      IF(JJ.LT.10.AND.JJ.GE.0) GO TO 92
      GO TO 150
92    K=KKK
      GO TO 90
C
150   STOP
      END
```

LAT	LONG	BANK	PITCH	
36.4	-11.4	.000	.000	
36.4	-11.4	.000	.000	
36.4	-11.4	.000	.000	.6 sec no movement
36.4	-11.4	.000	.000	
36.4	-11.4	.000	.000	
36.4	-11.4	.001	.001	
36.4	-11.4	.003	.003	
36.4	-11.4	.005	.005	
36.4	-11.4	.007	.007	.9 sec movement
36.4	-11.4	.018	.018	
36.4	-11.4	.018	.018	
36.4	-11.4	.019	.019	
36.4	-11.4	.017	.017	
36.4	-11.4	.013	.013	
36.4	-11.4	.005	.005	
36.4	-11.4	.000	.000	
36.4	-11.4	.000	.000	
36.4	-11.4	.000	.000	.8 sec no movement
36.4	-11.4	.000	.000	
36.4	-11.4	.000	.000	
36.4	-11.4	.007	.007	
36.4	-11.4	.007	.007	
36.4	-11.4	.000	.000	
36.4	-11.4	.003	.003	
36.4	-11.4	.005	.005	.9 sec movement
36.4	-11.4	.007	.007	
36.4	-11.4	.008	.008	
36.4	-11.4	.001	.001	
36.4	-11.4	.005	.005	
36.4	-11.4	.000	.000	
36.4	-11.4	-.004	-.004	
36.4	-11.4	-.006	-.006	

Fig. E-5. FORTRAN Program Verification Data

CONTINUED

36.4	-11.4	.003	.003	1.8 sec mo novement
36.4	-11.4	.003	.003	
36.4	-11.4	.003	.003	
36.4	-11.4	.003	.003	
36.4	-11.4	.003	.003	
36.4	-11.4	.003	.003	
36.4	-11.4	.002	.002	
36.4	-11.4	.003	.003	
36.4	-11.4	.003	.003	
36.4	-11.4	.003	.003	
36.4	-11.4	.006	.006	Example of smooth movement no recorded
36.4	-11.4	.007	.007	
36.4	-11.4	.008	.008	
36.4	-11.4	.009	.009	
36.4	-11.4	.010	.010	
36.4	-11.4	.011	.011	
36.4	-11.4	.010	.010	
36.4	-11.4	.009	.009	
36.4	-11.4	.000	.000	
36.4	-11.4	-.002	-.002	.9 sec movement
36.4	-11.4	-.003	-.003	
36.4	-11.4	-.004	-.004	
36.4	-11.4	-.007	-.007	
36.4	-11.4	-.008	-.008	
36.4	-11.4	-.012	-.012	
36.4	-11.4	-.015	-.015	
36.4	-11.4	-.010	-.010	

Fig. E-5--Continued

CONTINUED

36.4	-11.4	-.001	-.001	1.2 sec no movement
36.4	-.114	.000	.000	
36.4	-11.4	.000	.000	
36.4	-11.4	.000	.000	
36.4	-11.4	.000	.000	
36.4	-11.4	.000	.000	
36.4	-11.4	.000	.000	
36.4	-11.4	.000	.000	
36.4	-11.6	.000	.000	
36.4	-11.4	.000	.000	
36.4	-11.4	.000	.000	
36.4	-11.4	.000	.000	
36.4	-11.4	.005	.005	Not recorded by program because it was building when run ended
36.4	-11.4	.005	.005	
36.4	-11.4	.005	.005	
36.4	-11.4	.005	.005	
36.4	-11.4	.000	.000	Program does not look at last seven points on a run.
36.4	-11.4	.000	.000	
36.4	-11.4	.000	.000	
36.4	-11.4	.000	.000	
36.4	-11.4	.060	.060	
36.4	-11.4	.060	.060	
36.4	-11.4	.060	.060	

END
RESULTS OF RUN

NUMBER OF TIMES THE PITCH BASE WAS CHANGED =5
MBER OF TIMES THE BANK BASE WAS CHANGED =5

MBER OF PERIODS OF MOVEMENT =3
MBER OF PERIODS OF NO MOVEMENT =4

MBER OF TENTHS OF SECONDS = 71

NUMBER OF TENTHS NOT ACCOUNTED FOR = 4
MOVEMENTS
9 9 9
NO MOVEMENTS
6 8 18 12

Fig. E-5--Continued

Appendix F

Raw Data on Stick Movements

This appendix contains the raw data determined through the FORTRAN program in Appendix F. This data was used to determine the flight control input distributions for use in the model. Histograms of this data are presented in Appendix G. Data is in tenths of seconds.

1000 FEET, PILOT A , MOVEMENTS"

15	68	6	17	9	5	3	12	3	26
36	24	75	9	46	3	7	9	7	7
5	4	10	5	3	3	3	10	3	31
15	13	13	14	19	3	13	17	8	11
13	3	20	17	11	9	6	8	15	7
6	4	27	19	15	15	13	4	8	5
11	9	25	15	4	9	17	6	8	12
8	53	6	4	4	70	4	22	8	3
6	7	7	3	4	10	31	14	4	4
7	4	4	13	6	11	6	74	5	9
4	54	21	3	4	7	5	3	33	14
4	38	5	10	14	8	25	4	4	16
21	9	8	15	27	6	5	24	5	8
59	14	10	19	34	6	6	13	4	5
4	7	14	7	6	7	8	10	44	7
3	8	11	12	4	3	22	4		

1000 FEET, PILOT B , MOVEMENTS"

18	8	27	4	12	24	4	16	9	52
10	15	8	8	17	23	22	19	10	6
46	20	6	4	13	17	8	33	9	39
13	13	34	6	12	10	32	8	8	9
14	15	13	8	27	4	8	11	11	7
18	9	7	18	12	21	6	5	13	4
6	9	8	15	139	4	32	18	21	3
5	4	12	8	28	17	10	21	12	26
7	5	3	12	69	18	17	20	16	20
12	3	12	5	24	32	11	28	30	23
16	83	12	13	14	16	12	15	12	3
9	20	24	4	5	22	29	15	5	12
16	15	32	17	7	40	18	52	3	18
16	5	5	4	4	4	4	12	9	9
10	12	5	8	4	5	19	4	12	3
5	11	26	15	15	4	21	6		

1000 FEET, PILOT C , MOVEMENTS"

5	4	15	9	17	5	3	23	6	6
6	16	4	40	20	17	39	4	42	9
7	34	16	30	7	3	42	29	21	11
22	9	10	28	46	22	22	6	7	23
21	5	13	12	23	30	20	3	7	38
4	11	6	12	25	8	18	42	11	45
7	11	16	10	40	3	12	3	10	16
9	5	8	13	38	6	14	7	11	3
18	7	25	23	16	25	19	25	22	11
29	53	5	21	8	4	5	32	4	7
30	3	9	15	13	27	7	31	53	38
54	8	3	9	6	5	22	13	4	30
8	31	3	35	3	22	6	18	24	4
5	31	9	17	7	22	13	7	36	9
3	17								

(NUMBERS INDICATE TIME IN TENTHS OF SECONDS)

Fig. F-1. Raw Data, 1000 Feet, Stick Movements

1000 FEET, PILOT A, NO MOVEMENTS"

10	9	39	8	33	10	43	87	14	6
5	10	3	13	9	14	15	7	7	28
6	73	8	15	5	12	22	9	8	10
27	4	7	6	3	15	6	6	26	4
6	26	11	12	3	24	16	3	5	25
30	8	8	18	60	14	19	3	6	4
17	40	23	7	14	9	12	12	4	5
60	16	6	8	19	10	8	22	26	22
5	7	5	33	28	3	19	6	15	10
43	4	3	3	4	4	17	7	24	14
5	24	19	21	7	8	18	8	6	4
6	59	112	26	13	3	22	5	7	4
13	12	49	6	14	9	107	10	6	7
12	5	27	6	11	7	14	70	72	18
9	6	8	3	70	31	3	16	8	3
9	8	10	9	14	6	30			

1000 FEET, PILOT B, NO MOVEMENTS"

7	7	6	19	12	23	23	17	3	8
30	29	14	4	7	9	4	7	9	5
30	53	9	16	6	19	16	44	7	9
72	8	21	9	38	32	30	70	11	36
14	24	18	25	64	3	10	13	5	6
7	6	5	3	10	3	7	12	7	5
20	16	4	4	56	22	26	4	15	53
10	34	10	11	7	7	10	8	3	5
9	6	10	6	11	31	3	24	12	8
17	9	6	15	21	8	6	26	8	6
15	6	11	8	3	22	7	8	10	6
19	3	8	4	18	5	10	16	5	17
11	8	[illegible]	23	8	5	9	11	5	24
9	119	25	74	5	4	34	3	9	3
35	6	7	8	4	9	4	23	25	14
9	3	8	4	21	9	41	21		

1000 FEET, PILOT C, NO MOVEMENTS"

19	6	7	30	10	17	15	3	11	62
7	6	10	11	7	6	10	9	8	8
3	8	7	13	17	14	11	65	18	11
8	4	17	16	10	23	36	5	12	19
19	17	18	23	14	5	20	14	16	30
6	8	11	8	8	5	11	31	5	20
8	13	5	7	3	14	40	29	8	21
7	4	27	6	11	6	9	5	14	41
61	15	44	6	7	6	20	41	48	29
13	6	17	123	12	21	6	46	6	12
20	4	12	22	34	19	12	13	7	11
18	4	13	35	20	6	42	5	45	8
10	29	15	12	8	10	13	23	6	5
10	12	22	3	4	44	22	10	16	6
72									

(NUMBERS INDICATE TIME IN TENTHS OF SECONDS)

Fig. F-2. Raw Data, 1000 Feet, No Stick Movements

500 FEET, PILOT A, MOVEMENTS*

16	5	21	9	5	15	13	4	12	6
10	3	3	23	7	9	26	99	15	9
6	6	3	4	5	10	13	3	12	4
8	12	46	10	5	5	4	16	3	9
7	12	10	6	4	11	13	15	5	30
3	8	7	5	13	6	41	4	3	4
5	5	13	8	9	19	26	11	11	16
17	32	3	14	14	4	14	25	4	6
16	9	22	12	13	28	9	3	6	3
13	10	9	5	17	10	4	12	13	11
7	5	3	3	5	5	14	7	7	13
12	5	6	5	5	3	7	6	19	7
12	4	12	6	12	19	5	5	9	5
9	14	19	11	5	4	11	8	13	9
5	8	14	5	9					

500 FEET, PILOT B, MOVEMENTS*

40	51	42	10	4	4	37	9	28	15
57	21	7	24	11	43	5	34	14	104
13	13	17	21	3	25	85	4	28	18
4	47	13	4	21	8	30	14	6	4
5	7	6	19	4	16	5	4	30	10
27	7	9	10	4	6	20	48	92	8
11	35	64	6	15	19	4	22	11	16
5	5	7	4	9	17	21	9	12	29
3	4	28	13	16	3	15	7	83	12
6	68	26	24	22	26	4	21	4	17
13	33	17	4	4	14	23	18	13	13
6	17	9	18	128	6	9	23	59	13
13	18	24	50	29	53	22	27	48	11
60	14								

500 FEET, PILOT C, MOVEMENTS*

19	34	32	25	12	28	8	15	24	6
29	61	26	6	13	10	27	9	7	3
6	4	3	8	17	4	4	8	8	6
5	21	15	4	4	9	15	6	20	5
34	7	23	20	68	4	12	18	32	14
6	9	37	4	18	18	9	28	12	10
30	17	6	38	29	13	12	27	10	89
6	6	10	42	31	8	8	10	24	20
12	12	12	21	5	15	33	20	12	6
13	7	6	22	43	27	7	6	36	10
3	25	8	11	13	17	22	3	44	23
39	10	15	10	8	39	34	10	28	13
8	16	17	5	6	55	5	7	10	7
6	3	29	8	5	4				

(NUMBERS INDICATE TIME IN TENTHS OF SECONDS)

Fig. F-3. Raw Data, 500 Feet, Stick Movements

500 FEET , PILOT A ,NO MOVEMENTS"

22	6	31	29	24	9	35	26	12	34
9	9	11	5	5	9	6	6	3	11
0	22	6	10	46	11	37	10	50	5
25	6	47	12	24	7	15	28	3	99
46	28	9	59	12	14	7	30	4	19
6	23	6	3	13	6	4	7	4	5
18	10	40	3	6	5	36	26	5	56
18	10	14	31	131	10	19	16	10	9
14	41	15	10	8	31	31	35	6	19
18	0	21	56	18	63	6	63	13	29
16	0	33	7	55	5	6	26	58	11
15	60	10	25	15	15	13	5	52	20
5	7	56	21	4	43	6	71	9	9
4	22	6	20	8	19	6	33	7	39
19	24	47	6	9					

500 FEET , PILOT B ,NO MOVEMENTS"

22	4	3	4	20	7	24	7	16	9
4	10	4	4	3	17	10	22	3	26
65	33	15	3	59	4	3	6	3	25
13	26	9	11	50	12	9	9	6	4
10	3	4	7	24	28	3	4	15	3
11	43	8	3	9	3	5	20	34	25
4	37	4	16	13	11	26	7	18	5
6	4	10	25	16	11	11	3	9	61
8	7	17	16	5	7	9	5	4	8
3	22	4	22	3	14	31	15	19	18
3	32	13	7	15	5	4	15	16	13
30	29	28	18	5	6	56	15	15	6
12	8	3	24	23	11	13	4	6	17
16	17								

500 FEET , PILOT C ,NO MOVEMENTS"

5	20	23	14	3	30	6	21	21	12
13	25	9	7	7	14	55	16	83	13
7	6	5	10	28	6	15	5	33	8
5	26	100	31	7	11	33	4	10	13
7	7	8	41	5	4	6	19	7	11
6	30	8	5	7	34	6	17	12	7
3	53	15	4	9	12	22	31	12	3
36	6	5	11	6	4	55	6	59	107
15	3	26	7	7	8	30	41	3	18
15	22	7	6	31	51	6	3	6	12
5	9	4	3	5	7	7	6	9	39
19	35	25	41	7	35	11	16	35	10
47	8	10	13	20	6	8	19	8	4
15	13	10	23	3					

(NUMBERS INDICATE TIME IN TENTHS OF SECONDS)

Fig. F-4. Raw Data, 500 Feet, No Stick Movements

250 FEET, PILOT A ,MOVEMENTS"

13	13	20	5	12	8	14	6	8	31
18	9	12	6	8	6	16	6	4	5
8	11	3	7	12	3	11	4	8	10
10	3	17	18	49	7	20	3	12	13
14	6	21	4	17	3	25	17	16	35
4	6	12	7	16	4	6	5	3	8
7	12	13	7	6	4	15	17	5	31
5	45	20	9	79	7	15	10	12	16
3	5	19	13	19	3	4	29	21	19
17	4	20	9	25	9	15	14	11	9
4	6	8	33	17	13	26	11	5	4
4	4	4	11	5	5	14	4	5	3
13	5	4	4	3	6	25	3	4	4
6	6	8	3	4	10	12	3	6	16
4	5	4	4	3	3	3	6	13	12
9	7	19	10	5	22	16	7	8	11
42	4	5	12	9	13	37	5	14	11
10									

250 FEET, PILOT B ,MOVEMENTS"

1	44	39	28	4	24	3	38	30	29
7	6	11	53	15	16	36	32	7	6
33	10	26	57	43	18	18	40	9	4
38	27	19	32	16	24	5	13	12	22
3	20	11	6	16	35	3	3	10	6
3	6	8	54	9	5	19	72	7	8
16	12	33	4	12	13	12	9	13	40
48	23	3	14	20	97	25	18	18	8
25	59	11	6	53	5	13	16	9	18
18	20	4	3	5	8	44	40	9	9
21	3	20	16	3	3	30	15	37	31
9	17	11	11	10	9	18	19	3	11
9	17	45	7	25	11	6	22	5	3
4	13	7	10	15	7	47	3	3	12
21	17	10	21	5	5	6	17	14	12
23	3	5	8	15	9	8	9	16	

250 FEET, PILOT C ,MOVEMENTS"

1	24	16	7	3	17	6	12	9	7
13	7	5	5	5	29	16	3	46	23
10	22	43	23	20	42	10	16	17	7
8	37	5	10	6	8	23	14	49	3
30	4	32	21	34	15	3	4	10	30
25	10	8	24	7	8	11	8	6	8
6	8	6	3	6	3	27	20	12	7
11	13	23	12	20	12	35	7	3	15
18	4	19	14	10	9	8	25	4	6
11	5	30	5	5	6	4	4	10	7
19	3	27	18	3	13	20	20	8	11
3	12	20	6	25	4	9	7	15	3
10	27	15	7	6	21	5	14	16	8
26	24	9	6	23	3	4	19	5	69
5	15	12	6	15	93	6	4	21	6
14	4	19	3	7	11	5			

(NUMBERS INDICATE TIME IN TENTHS OF SECONDS)

Fig. F-5. Raw Data, 250 Feet, Stick Movements

500 FEET , PILOT A ,NO MOVEMENTS"

22	6	31	29	24	9	35	26	12	34
9	9	11	5	5	9	6	6	3	11
8	22	6	10	46	11	37	10	50	5
25	6	47	12	24	7	15	28	3	99
46	28	9	59	12	14	7	30	4	19
6	23	6	3	13	6	4	7	4	5
18	10	40	3	6	5	36	26	5	56
18	10	14	31	131	10	19	16	10	9
14	41	15	10	8	31	31	35	6	19
18	8	21	56	18	63	6	63	13	29
16	8	33	7	55	5	6	26	58	11
15	60	10	25	15	15	13	5	52	20
5	7	56	21	4	43	6	71	9	9
4	22	6	20	8	19	6	33	7	39
19	24	47	6	9					

500 FEET , PILOT B ,NO MOVEMENTS"

22	4	3	4	20	7	24	7	16	9
4	10	4	4	3	17	10	22	3	26
65	33	15	3	59	4	3	6	3	25
13	26	9	11	50	12	9	9	6	4
10	3	4	7	24	28	3	4	15	3
11	43	8	3	9	3	5	20	34	25
4	37	4	16	13	11	26	7	18	5
6	4	10	25	16	11	11	3	9	61
8	7	17	16	5	7	9	5	4	8
3	12	4	22	3	14	31	15	19	18
3	32	13	7	15	5	4	15	16	13
30	29	28	18	5	6	56	15	15	6
12	8	3	24	23	11	13	4	6	17
16	17								

500 FEET , PILOT C ,NO MOVEMENTS"

5	20	23	14	3	30	6	21	21	12
13	25	9	7	7	14	55	16	83	13
7	6	5	10	28	6	15	5	33	8
5	26	100	31	7	11	33	4	10	13
7	7	8	41	5	4	6	19	7	11
6	30	8	5	7	34	6	17	12	7
3	53	15	4	9	12	22	31	12	3
36	6	5	11	6	4	55	6	59	107
15	3	26	7	7	8	30	41	3	18
15	22	7	6	31	51	6	3	6	12
5	9	4	3	5	7	7	6	9	39
19	35	25	41	7	35	11	16	35	10
47	8	10	13	20	6	8	19	8	4
15	13	10	23	3					

(NUMBERS INDICATE TIME IN TENTHS OF SECONDS)

Fig. F-6. Raw Data, 250 Feet, No stick Movements

Appendix G

Histograms on Stick Movements and Non-Movements

This appendix contains nine figures which display histograms of the stick movements and non-movements for each pilot at each altitude.

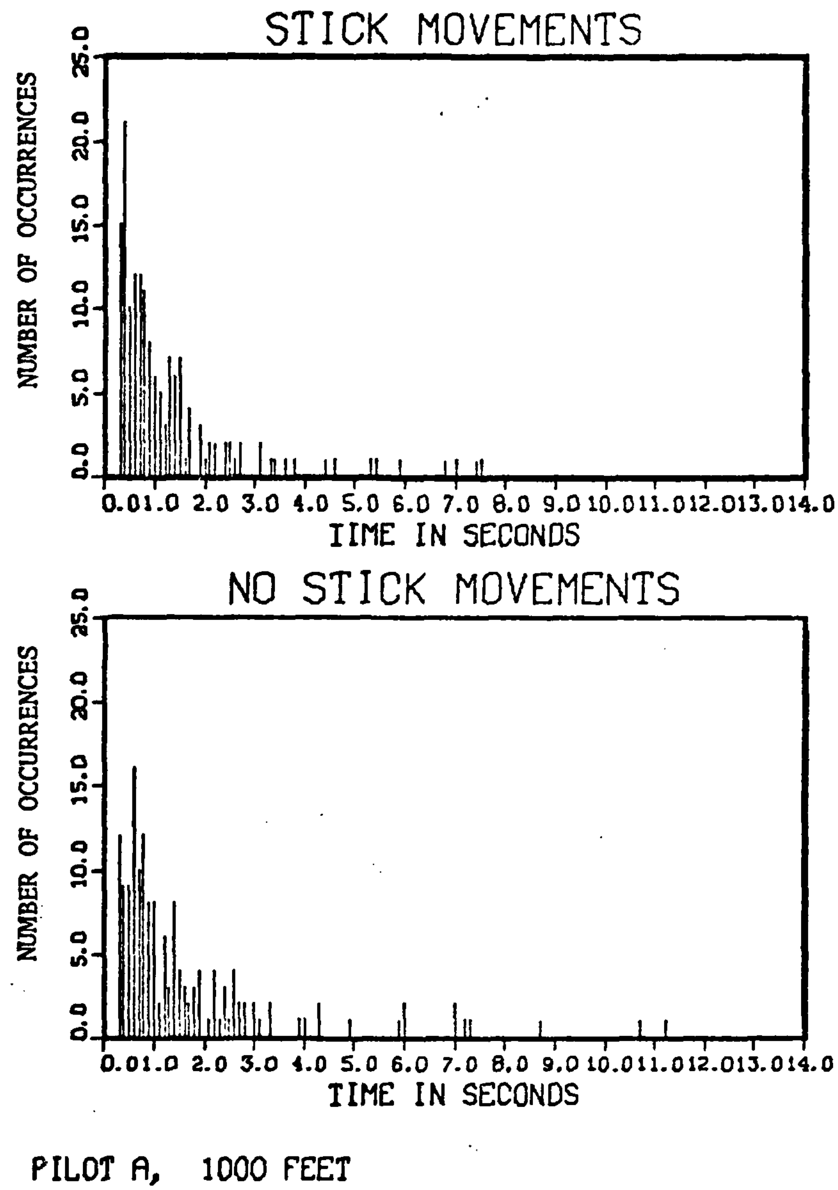
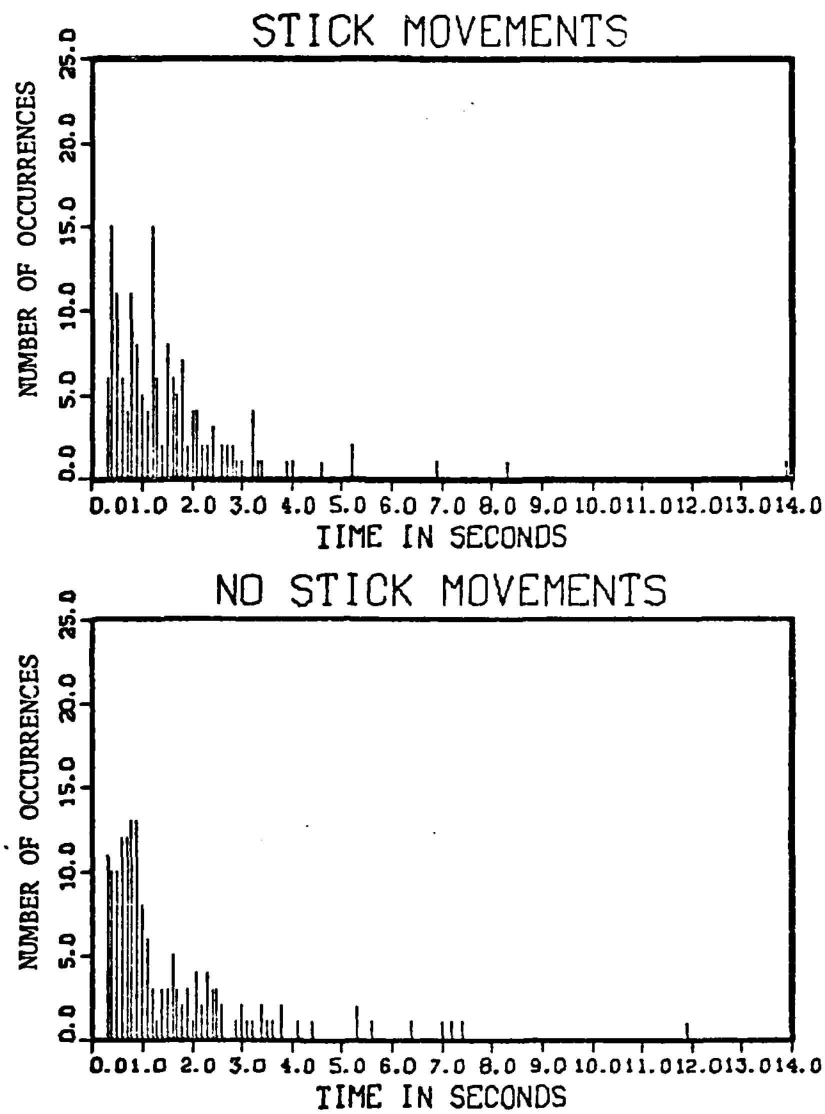


Fig. G-1. Distributions, Pilot A, 1000 Feet



PILOT B, 1000 FEET

Fig. G-2. Distributions, Pilot B, 1000 Feet

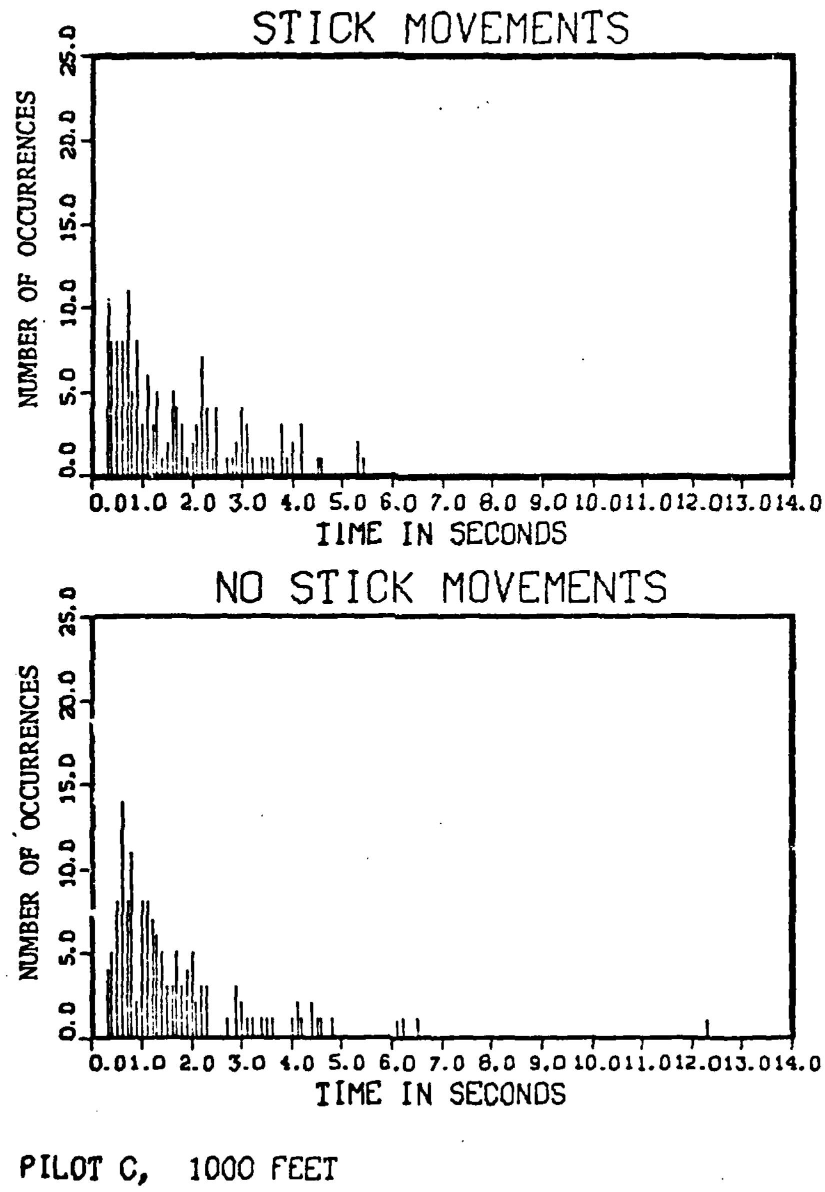


Fig. G-3. Distributions, Pilot C, 1000 Feet

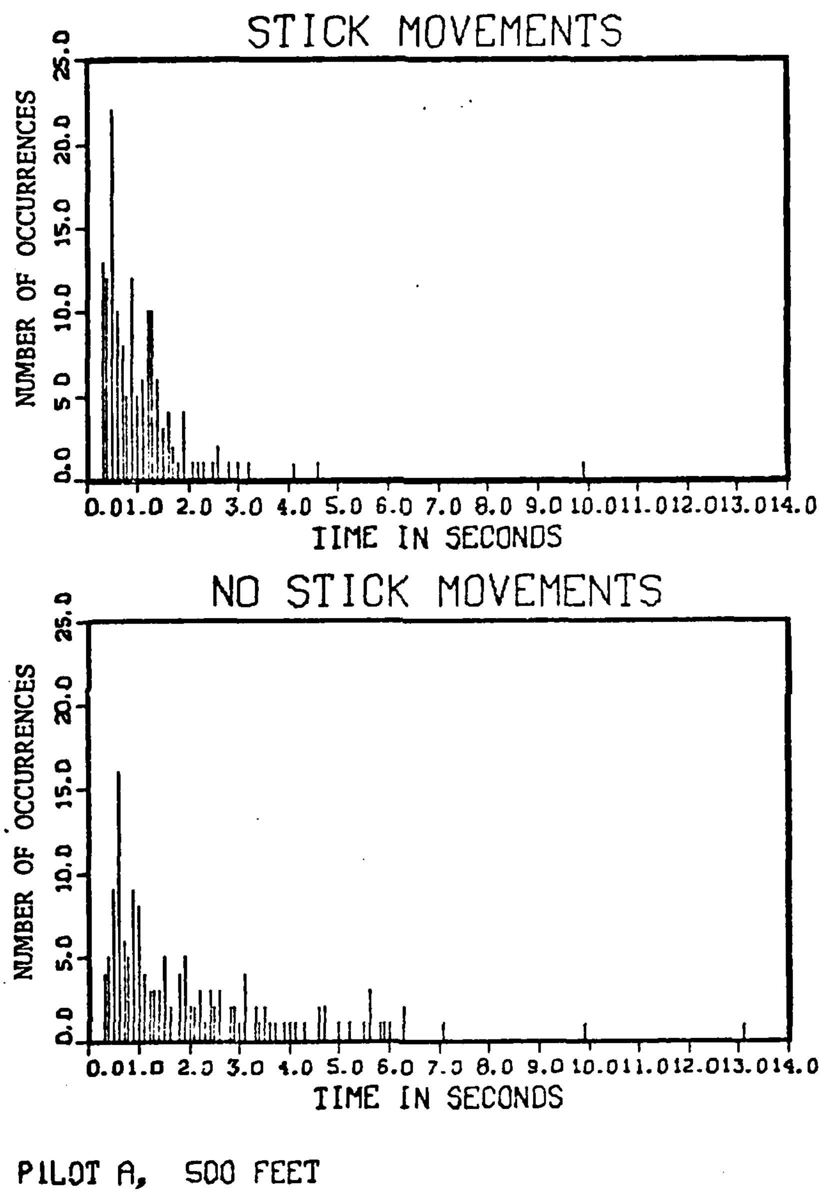


Fig. G-4. Distributions, Pilot A, 500 Feet

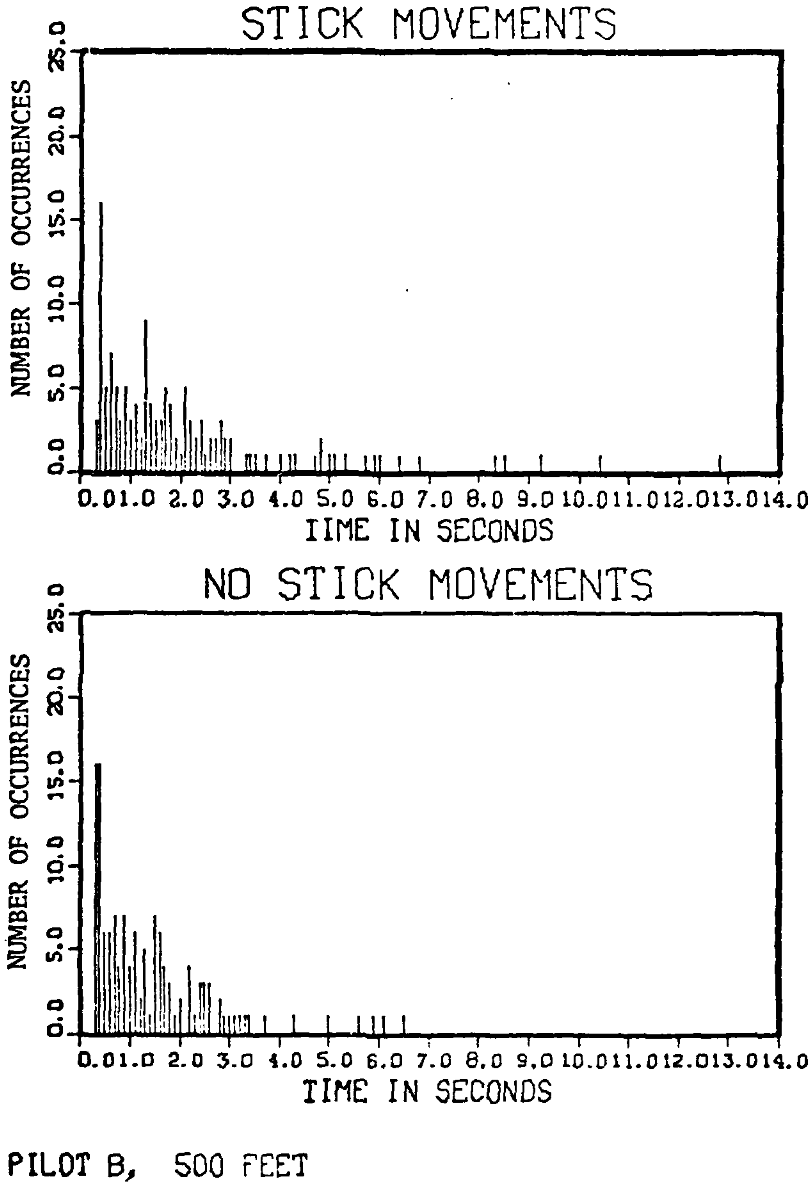


Fig. G-5. Distributions, Pilot B, 500 Feet

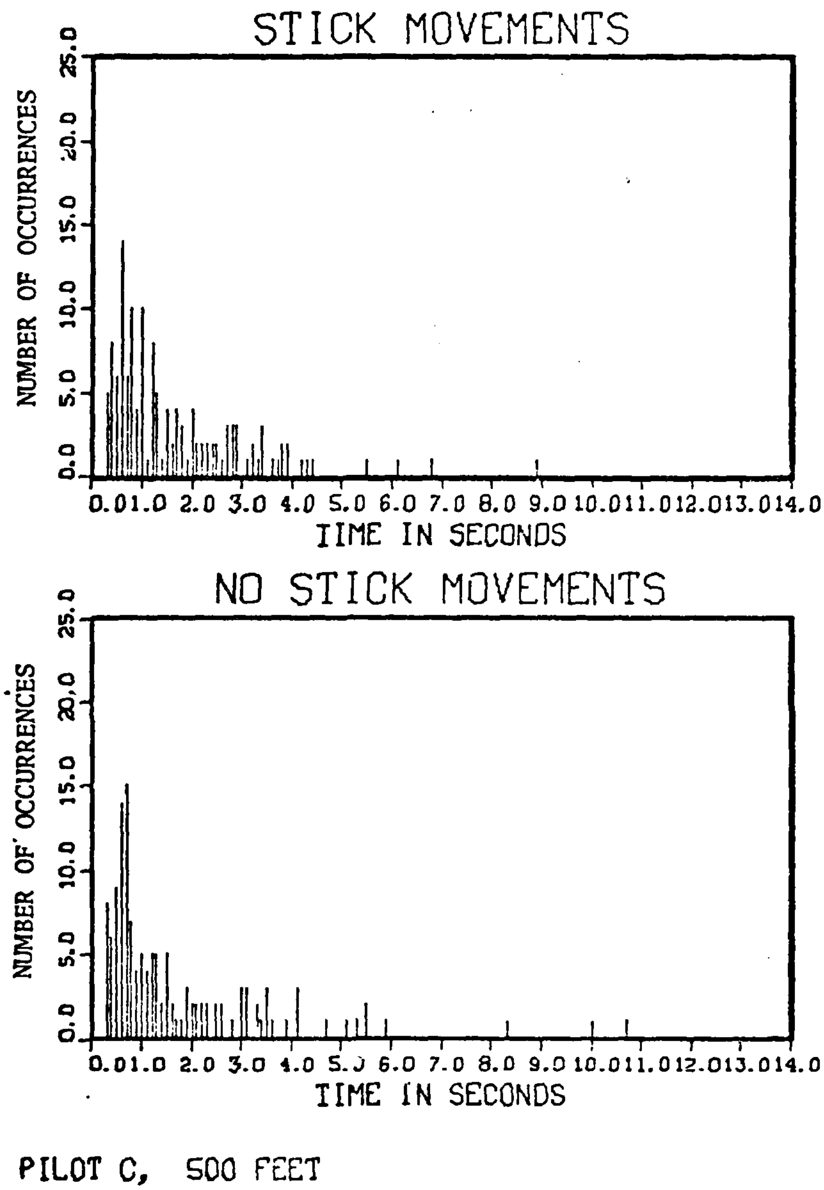


Fig. G-6. Distributions, Pilot C, 500 Feet

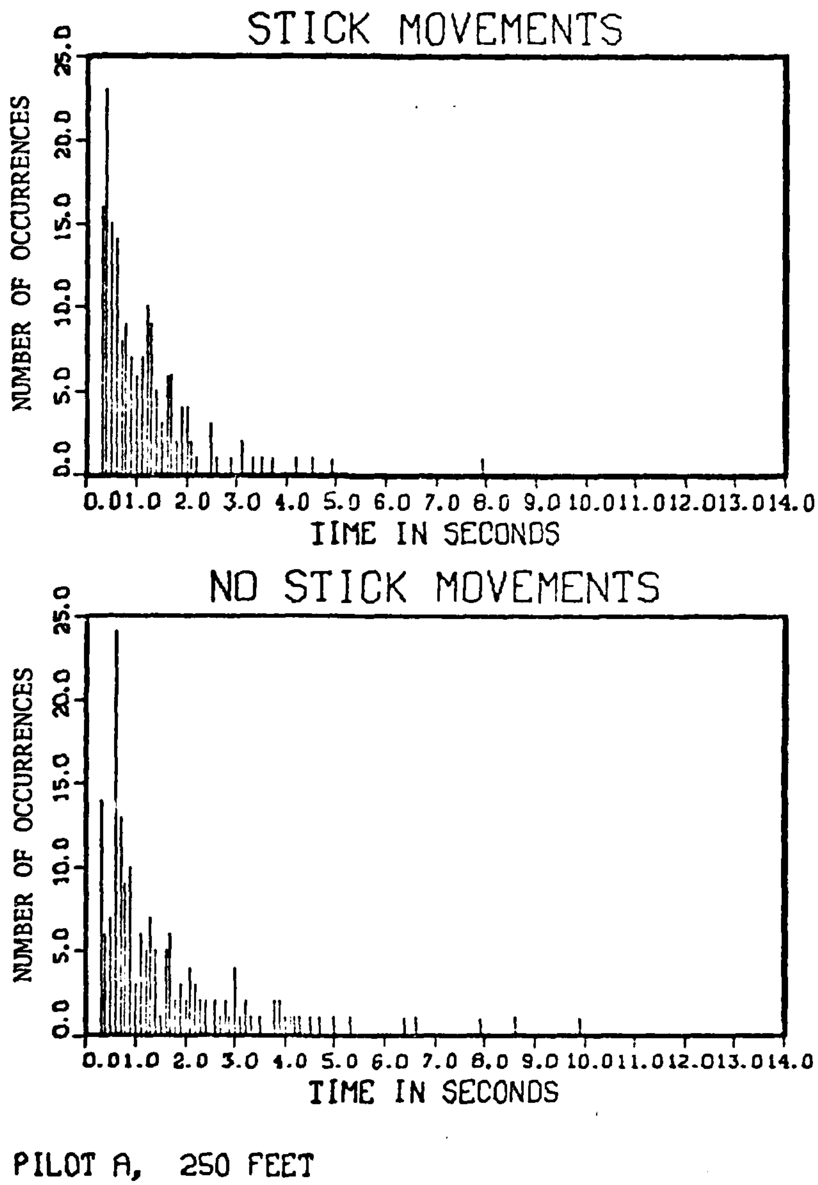


Fig. G-7. Distributions, Pilot A, 250 Feet

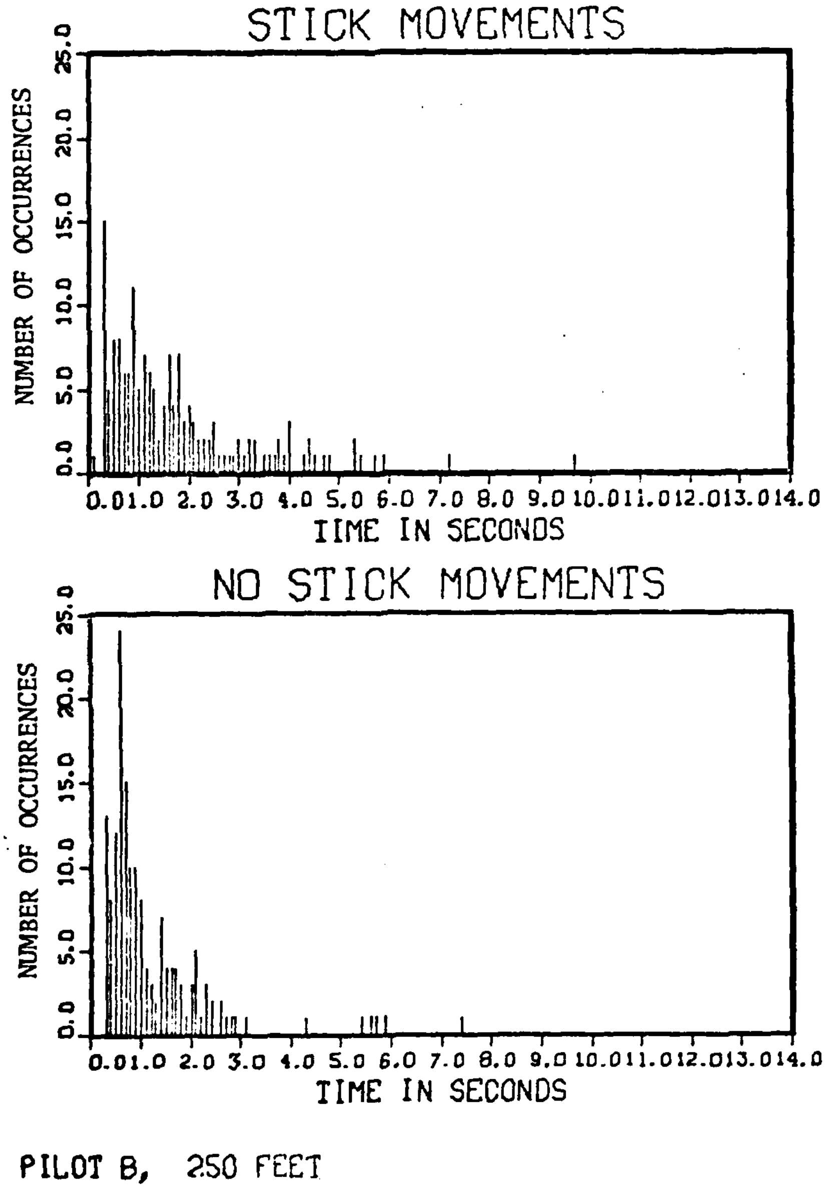
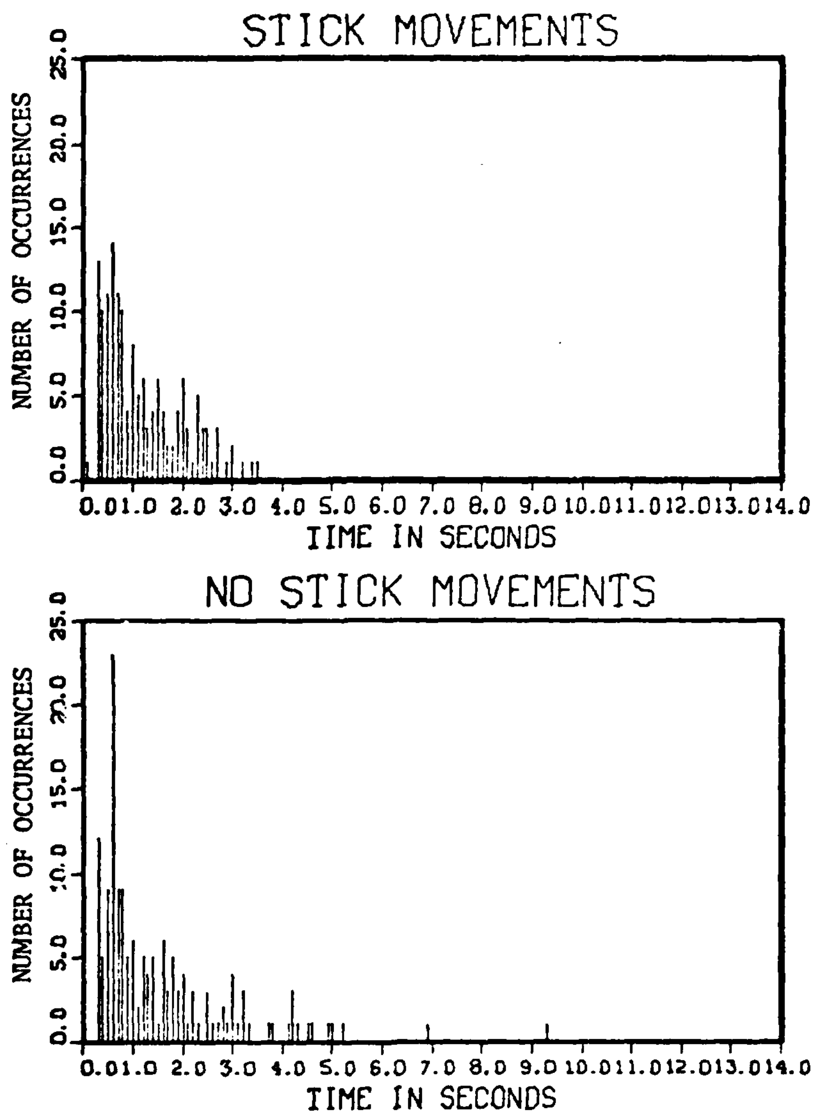


Fig. G-8. Distributions, Pilot B, 250 Feet



PILOT C, 250 FEET

Fig. G-9. Distributions, Pilot C, 250 Feet

Appendix H

K-S Tests of Aircraft Control Movement Distributions

This appendix contains the Kolmogorov-Smirnov test results used to compare individual pilot data between altitudes and between pilots.

TABLE X

K-S TWO-SAMPLE TEST
(p = probability)

	Stick Movements	No Stick Movements
1000 FEET		
Pilot A with Pilot B	p = .007	p = .978
Pilot A with Pilot C	p = .001	p = .277
Pilot B with Pilot C	p = .140	p = .081
500 FEET		
Pilot A with Pilot B	p = .000	p = .022
Pilot A with Pilot C	p = .000	p = .212
Pilot B with Pilot C	p = .223	p = .172
250 FEET		
Pilot A with Pilot B	p = .001	p = .125
Pilot A with Pilot C	p = .133	p = .996
Pilot B with Pilot C	p = .100	p = .047

TABLE XI

K-S TWO-SAMPLE TEST
(p = probability)

	Stick Movements	No Stick Movements
PILOT A		
1000 Feet with 500 Feet	p = .130	p = .074
1000 Feet with 250 Feet	p = .877	p = 1.0
500 Feet with 250 Feet	p = .116	p = .084
PILOT B		
1000 Feet with 500 Feet	p = .064	p = .354
1000 Feet with 250 Feet	p = .575	p = .320
500 Feet with 250 Feet	p = .617	p = .158
PILOT C		
1000 Feet with 500 Feet	p = .994	p = .390
1000 Feet with 250 Feet	p = .175	p = .544
500 Feet with 250 Feet	p = .387	p = .983

Appendix I

Analysis of Variance Procedure Results

This appendix contains SPSS ANOVA output for the two-way ANOVA and the one-way ANOVA with a Duncan's Multiple Range Test.

RESULTS OF THE TWO-WAY ANOVA

* * * * * * * * * A N A L Y S I S   O F   V A R I A N C E * * * * * * * * *

TIME
BY ECM
ALT

* *

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F	
MAIN EFFECTS	274464.990	4	68616.247	33.861	.001	
ECM	10333.244	2	5166.622	2.550	.084	not sig.
ALT	264131.746	2	132065.873	65.172	.001	significant
2-WAY INTERACTIONS	2439.377	4	609.844	.301	.877	
ECM ALT	2439.377	4	609.844	.301	.877	not sig.
EXPLAINED	276904.367	8	34613.046	17.081	.001	
RESIDUAL	182376.669	90	2026.407			
TOTAL	459281.036	98	4686.541			

RESULTS OF THE ONE-WAY ANOVA

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQ.	MEAN SQ.	F RATIO	F PROB	
BETWEEN GROUPS	8	276904.367	34613.046	17.081	.000	significant
WITHIN GROUPS	90	182376.669	2026.407			
TOTAL	98	459281.036				

GROUP	COUNT	MEAN	STAND. DEV.	STAND. ERROR	MIN.	MAX.	95 PERCENT CONF INT FOR MEAN
GRP 1	11	1194.00	26.05	7.85	1157.61	1222.78	1176.50 TO 1211.51
GRP 2	11	1205.41	39.50	11.91	1157.69	1279.90	1178.88 TO 1231.95
GRP 3	11	1203.81	39.83	12.01	1150.21	1264.54	1177.06 TO 1230.57
GRP 4	11	1185.43	35.62	10.74	1124.77	1252.34	1161.50 TO 1209.37
GRP 5	11	1197.07	33.75	10.18	1137.08	1244.70	1174.40 TO 1219.74
GRP 6	11	1218.32	33.61	10.13	1163.69	1269.40	1195.74 TO 1240.90
GRP 7	11	1292.53	61.91	18.67	1179.81	1381.00	1250.94 TO 1334.12
GRP 8	11	1313.72	44.74	13.49	1242.40	1368.66	1283.66 TO 1343.77
GRP 9	11	1324.49	71.00	21.41	1262.48	1514.33	1276.79 TO 1372.19
TOTAL	99	1237.20			1124.77	1514.33	

RESULTS OF THE DUNCAN MULTIPLE RANGE TEST

```
MULTIPLE RANGE TEST


DUNCAN PROCEDURE
RANGES FOR THE .050 LEVEL -
   2.81  2.96  3.05  3.12  3.18  3.23  3.27  3.30

  THE RANGES ABOVE ARE TABULAR VALUES.
THE VALUE ACTUALLY COMPARED WITH  MEAN(J)-MEAN(I) IS..
     31.8309 * RANGE * SQRT(1/N(I) + 1/N(J))

  HOMOGENEOUS SUBSETS  (SUBSETS OF GROUPS, WHOSE HIGHEST AND LOWEST MEANS DO
NOT DIFFER BY MORE THAN THE SHORTEST SIGNFICANT RANGE FOR A
SUBSET OF THAT SIZE)

  SUBSET  1

  GROUP   GRP  4    GRP  1    GRP  5    GRP  3    GRP  2    GRP  6
MEAN 1185.4330 1194.0050 1197.0692 1203.8124 1205.4133 1218.3162
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

SUBSET  2

  GROUP   GRP  7    GRP  8    GRP  9
MEAN 1292.5285 1313.7167 1324.4883
- - - - - - - - - - - - - - - - - -
```

Groups 1-6 = All ECM levels at 250 and 500 feet AGL.

Groups 7-9 = All ECM levels at 1000 feet AGL.

Groups 1-6 have a statistically lower workload than groups 7-9.

Appendix J

Analysis of Variance Procedure Assumption Tests

This appendix contains the tests made on the data used in the ANOVA to confirm the applicability of the procedure. The tests included are:

1. A Runs Test for Independence.
2. A Hartley F-max Test for Constant Variance.
3. A Kolmogorov-Smirnov Test for Normality of Residuals.

Test for Independence

A Runs Test (Ref 6:688) was used to confirm the independence of the data points used in the ANOVA.

Data Cell	Point Above Mean	Point Below Mean	Runs Allowable	Runs Observed
1	7	4	2-	7
2	6	5	3-10	8
3	5	6	3-10	8
4	8	3	2-	6
5	7	4	2-	6
6	6	5	3-10	8
7	8	3	2-	5
8	7	4	2-	5
9	5	6	3-10	9

Test for Constant Variance

The Hartley F Max Test (Ref 6:384) was used to confirm the constant variance.

Test statistic (Ref 6:718) for eleven samples, nine treatments, $\alpha = .05$.

9.45

Observed value from ANOVA output

8.28

H_0: Variance between each cell is constant.

H_1: Variance is not constant between cells.

$8.28 < 9.45$

Fail to reject H_0.

Test for Normality

The K-S Test was used to evaluate the normality of the data in each cell. Nine tests were run.

H_0: the 11 data points in each cell can be characterized by a normal distribution.

H_1: the 11 data points in each cell cannot be characterized by a normal distribution.

Data Cell	Observed Statistic	Test Statistic	Result
1	.2284	.3910	Fail to reject
2	.1952	.3910	Fail to reject
3	.1950	.3910	Fail to reject
4	.1523	.3910	Fail to reject
5	.1985	.3910	Fail to reject
6	.1692	.3910	Fail to reject
7	.1863	.3910	Fail to reject
8	.1408	.3910	Fail to reject
9	.1408	.3910	Fail to reject

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A SIMULATION TO ANALYZE PILOT WORKLOAD IN AN ELECTRO-OPTICAL, N--ETC(U)
MAR 81 A W GROVES, R L KAERCHER
UNCLASSIFIED AFIT/GST/OS/81M-5 NL

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Vitas of the Authors

Anthony W. Groves was born on 21 August 1946 in Vallejo, California. As the son of an Air Force officer, he lived at various locations throughout childhood. He graduated from high school in Tucker, Georgia and then attended Texas A&M University, where he received a Bachelor of Science Degree in Aerospace Engineering in January 1969. After graduation, he attended Undergraduate Navigator Training and received his wings in October 1969. After three years as a Weapon Systems Officer in the F-4, he attended pilot training at Sheppard AFB, Texas. After graduating he returned to the F-4 at Holloman AFB, New Mexico. He was subsequently assigned to fly F-4C Wild Weasel aircraft at Spangdalem AB, Germany from 1976 to 1979. He entered the Air Force Institute of Technology in August 1979.

He is married to the former Janis Dianne Holder of Universal City, Texas. They have a daughter, Holly and a son, Adam.

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Richard L. Kaercher was born 29 September 1941 in Fargo, North Dakota. He graduated from high school in Fargo in 1959 and attended North Dakota State University from which he received a Bachelor of Science Degree in Mechanical Engineering and his commission in the United States Air Force through the Reserve Officer Training Program in May 1964. He entered the Air Force on active duty in November 1964 and graduated from pilot training at Reese AFB, Texas in December 1965. He flew F-4s in Germany from 1966 to 1967 and in Thailand in 1968. He served as an instructor in the T-38 at Loredo AFB, Texas from 1969 to 1971. He was an instructor in the F-5 at Williams AFB, Arizona from 1971 to 1975. In August 1975 he was assigned to the 57th FIS at Keflavik, Iceland where he flew F-4s. He was stationed at Bergstrom AFB, Texas in Twelfth Air Force STAN/EVAL as a flight examiner in F-5s and the T-38 Lead-In Fighter from September 1976 until entering the Air Force Institute of Technology in August 1979.

He is married to the former Murtha Jean Bateman of Fargo, North Dakota; they have two boys, Gene and Brandon.

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